FAO Fisheries Technical Paper No. 171 FIRS/T171(En)

SURVEY METHODS OF APPRAISING FISHERY RESOURCES

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FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS
Rome 1977

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M-43

ISBN 92-5-100516-8

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PREPARATION OF THIS DOCUMENT

In the past, FAO has produced several manuals dealing separately with the various aspects and methods of conducting surveys of marine fish stocks. The purpose of this manual is to provide a concise and comprehensive overview of the objectives that can be achieved by surveys and the methods available for conducting them, along with advice on how to make the necessary choices among alternative objectives and methods and how to plan and conduct an effective survey according to the circumstances of each case.

This manual was prepared by Mr. A. Saville of the Marine Laboratory, Aberdeen, in consultation with the staff of the Fishery Resources and Environment Division of FAO and with the collaboration of the Contributors listed in the Introduction.

Distribution:

FAO Department of Fisheries
Regional Fisheries Officers
Selector SM
ACMRR Members
IOC
Author

Bibliographic References:

Saville, A. (Ed.)(1977)
FAO Fish.Tech.Pap., (171):76 p.
Survey methods of appraising fishery resources

Fishery surveys. Methodology. Stock assessment. Fishery resources. Exploratory fishing. Echo surveys. Primary production. Ichthyoplankton surveys. Stomach content. Data acquisition. Data processing. Potential yield.

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1. INTRODUCTION

Since the end of the Second World War there has been great interest in assessing the potential food resources which can be harvested from the oceans. This interest has stemmed from two sources: the depletion of traditional fishing grounds, which have been over-exploited by the long established and highly efficient fishing industries of the developed countries, and the interest of nations with less developed fishing industries in increasing their harvest of protein foods from seas adjacent to their coastlines. This interest is likely to receive an increased impetus in the immediate future from developments in the Law of the Sea as nations attempt to obtain more precise assessments of the total marine resources available within their extended zones of exclusive fisheries jurisdiction.

As a result of these pressures there have been, in the last thirty years, a large number of surveys carried out in the oceans of the world, to assess what new resources are available for exploitation, and which of the known resources are capable of providing greater yields by expanding the areas being fished. Such surveys have been carried out by a variety of national and international agencies and FAO has frequently had a hand in initiating, conducting and reporting on such surveys over a wide range of marine areas.

Such resource surveys, however, can be difficult to interpret and apply in e.g. development planning, and indeed even misleading unless the objectives they set out to achieve are clearly defined, are realistic in relation to the manpower and equipment available to carry them out. Moreover, the subsequent planning, and implementation of the plan, must be geared to achieving these objectives. The realization that many of the surveys which have been done in the past achieved little in relation to what could potentially have been gained, stimulated FAO to publish a series of manuals on resource surveys (Alverson 1971, Mackett 1973, Gulland 1975) which have set out ways of improving the quality of the data obtained from such surveys. However, there have been major advances in fisheries science since the earlier of these manuals was written, and accordingly it was decided, in 1976, that they should be updated and incorporated into a single volume covering all the major aspects of resource surveys. The present manual owes much to these earlier authors and indeed is a revision of their work rather than a completely fresh approach to the subject.

1.1 Survey Objectives

The objectives of a fishery resource survey will to a large extent depend on the stage of development of the fisheries in the area under consideration and the current state of knowledge of the resources these fisheries are exploiting. Basically such a survey can provide information on any of the following items, though rarely will it be possible to get useful information on all the items from the same survey:

(a) what species of fish are available in the area;
(b) what is their distribution within the area and how does it vary seasonally and spatially;
(c) what catch rate (i.e. catch per boat per unit time period) can be achieved and how this varies seasonally and over the area;
(d) what is the size of the resource, and of that part of it which is exploitable;
(e) what fishing techniques are best suited to catching the resource;
(f) what is the anticipated annual sustainable yield.

The nature of the survey will be determined by which questions most urgently need to be answered, since the answers to some questions will require a survey design different from that required by others. No single survey design can provide all the answers. Thus the first stage in designing a survey is to identify its objectives clearly.

The relative importance of each kind of information will be largely dependent on the stage of development reached by the fishing industry at the time the survey is carried out. In an area where the resources are unexploited or at a low level of exploitation the first priority will probably be providing information on the species available, their areal and seasonal distribution, the likely catch rates, and what methods are most appropriate to catching them, with a view to stimulating the investment necessary to start, or expand the area of operation of, a fishery. At this stage a rough indication of the likely sustainable yield will also be useful as a guide to whether further study or increased investment in the fishery is likely to be justified. As development proceeds, the objective will increasingly be directed to more refined assessments of the size of the resource, the sustainable yield from it, and the optimum management strategy so as to set the scale, and direction, of future investment in, and development of, the industry and in particular to ensure that investment does not unwittingly exceed the level that the resource can sustain. This has happened all too frequently in the past in many parts of the world and the difficulties of subsequently correcting it are apparent in the depleted state of many of the major world marine resources.

In this manual we are concerned only with surveys which are aimed at achieving the objectives listed above, that is with what Alverson (1971) called "Exploratory fishing surveys" and Gulland (1975), more appropriately, termed "Resource appraisal surveys". In fisheries science there are other possible survey objectives, such as monitoring annual or longer term changes in the size or composition of stocks or assessing the relative efficiencies of modified fishing gears. These, however, are normally the concern of highly developed fisheries whereas we are primarily concerned with stimulating the development of fisheries on latent or under-utilized resources.

If a resource appraisal survey is to continue over several years, however, at the same time as a commercial fishery is developing, the results of the survey can also be used to provide some monitoring of the effect of the fishery on the stock.

In the initial planning stage it is vital that the primary objectives should be clearly defined, and that these should be related to the current status of the fisheries in the area, to the aspirations of the government or of the industry for future expansion, and above all to the resources available to carry out the survey. These objectives are likely to be largely defined by the government, or other agency, which is financing the survey. But the scientist responsible for carrying it out should be fully consulted at an early stage to ensure that they are realistic, both in relation to the likely future requirements of the industry as it develops, and to the resources at his disposal for achieving them.

Resource surveys are inevitably costly to mount and those paying this cost are entitled to expect reliable outputs of information which will be of practical value in guiding their future investment and management strategy. It frequently happens that in survey planning highly desirable, but secondary, objectives are allowed to encroach on the resources of time, manpower and equipment available, to the extent that the main objectives become submerged and insufficient effort is devoted to any single objective to achieve results which are sufficiently valid to be practically useful. A survey with a multiplicity of objectives is unlikely to achieve other than roguhly indicative results from any of them. It is therefore essential at the initial planning stage to define the parameters which are to be measured and set them in order of priority.

1.2 Organization of this Manual

Whilst surveys must be planned and organized in accordance with their objectives, in a manual such as this it is more practicable and convenient to discuss the methods and procedures available in separate chapters. The reader can then decide which method or combination of methods is most suitable for achieving his objectives, bearing in mind the resources which are available to the survey which he is conducting.

The following chapters deal with:

Exploratory Fishing Surveys, from the initial planning stage to the details of their implementation;

Acoustic Surveys, at various levels of sophistication of equipment;

Indirect Methods of Forecasting Potential Yields from Fisheries, using measures of basic productivity, egg and larval surveys, or stomach contents of higher trophic animals;

Data Collection and Recording, a vital element in the subsequent interpretation and reporting of the results of any survey;

Data Analysis and Reporting, which is the culmination of all the preceding survey activities but for which the outputs are only as good as the initial inputs to it from them.

Conclusions and General Considerations on Choice of Survey Methods, including advice on the definition of survey objectives and choice of methods in light of the information presented in the previous chapters.

I should like to express my great gratitude to Mr. A. Corten, Ijmuiden, for preparing the first draft of Chapter 2, Professor R.E. Thorne, Seattle, of Chapter 3, Dr. O. Dragesund, Bergen, of Chapter 4, and Mr. W.B. Hall, Aberdeen, of Chapter 5.

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2. EXPLORATORY FISHING SURVEYS

2.1 Exploratory Fishing Surveys and Related Types of Surveys

The term "exploratory fishing survey" is generally used for the investigation of grounds which have not previously been fished, in order to describe what species of fish are available for capture, to estimate the absolute abundance of the stocks, to make a first estimate of their potential yield and to provide a preliminary rough estimate of the likely catch per boat. Once a fishing industry has been developed in the area there may still be a need for fishing surveys by research vessels in order to monitor changes in the stock abundance under the impact of fishing, or to estimate the strength of recruiting year-classes to the fishery as the basis for subsequent management. A fairly wide range of different research vessel activities have been loosely defined under the heading exploratory fishing surveys. These include the following categories:

1) Fisheries scouting: the use of survey vessels to locate concentrations of commercial fish and pass on the information to the commercial fishing fleet.

2) Experimental fishing: activities aimed at designing the best type of equipment and the best fishing strategy for increasing the efficiency of a particular fishery.

3) Prospecting surveys: aimed at providing estimates of the likely catch rates in the area using a particular type of vessel and gear.

4) Resource appraisal surveys: designed to provide information on what species are available to a fishery and first estimates of their abundance, distribution, and the size of the potential annual yield.

5) Resource monitoring surveys: aimed at studying year to year and longer term changes in the abundance and distribution of the stocks.

In this chapter we are primarily concerned with category 4 - Resource appraisal surveys but the data collected on such surveys can frequently be used to monitor changes in abundance and distribution.

The basic difference between resource appraisal surveys and resource monitoring surveys is that in the former absolute estimates of the resources are required. In an exploited stock in contrast, it is often sufficient to monitor relative changes in abundance from one year to another. Fish abundance can be expressed in numbers caught per hour fishing with a standard gear, and these values are compared to the long term mean. These surveys are generally carried out on a routine basis at the same time each year.

Although there are differences in objectives between resource appraisal surveys and resource monitoring surveys, in practice they are very similar in methodology. The methods described in this chapter apply equally to both types of surveys, and no further distinction between the two will be made.

2.2 Defining the Survey Objectives

Survey objectives will generally be specified to a large extent in the terms of reference of the project. The administrators who have commissioned the project will state which area should be covered by the survey, and frequently what species of fish they are interested in. The primary aim will be to investigate the distribution pattern of the species concerned, and to estimate its abundance over the whole area in absolute terms. In a new area, a first estimate of the potential annual production can be derived from an estimate of the virgin stock biomass:

$Y = 0.5\ M\ B_o$ (Gulland, 1975)

in which Y = maximum sustainable yield

B_o = unexploited standing stock biomass

M = natural mortality coefficient

Another objective will be to collect biological data on the species that we are dealing with. These data are used in separating different unit stocks, following migration of the fish, studying their reproductive cycle, and making more refined stock assessments by using information on age structure, growth and mortality rates. Types of data required are: age determinations, length and weight, maturity stage, fat content, parasites, meristic characters, etc. It may also be possible to conduct plankton sampling for eggs and larvae during the same survey.

A third objective may be the collection of environmental data. These may be of value in investigating the relationship between fish distribution and certain environmental parameters such as salinity, temperature, nutrient content, turbidity, plankton abundance, etc.

Although such data may be of value if a clear relationship can be established between them and fish distribution and abundance, they pose the risk that too much of the available time is spent on them, at the cost of the major objective. Sometimes, the objectives specified in the terms of reference are far too extensive in comparison with the amount of vessel time and manpower available. In such cases, it is necessary to set priorities among the various objectives in the following way:

1) Estimating the abundance and distribution of the species over the whole survey area. This requires that much attention should be given to the selection and testing of an appropriate sampling gear. Moreover, the available vessel time should be used to make as large a number of hauls as possible (see paragraphs 2.4 - 2.6).

2) Biological data collection. This is a valuable by-product of the survey, as long as it does not affect the number of hauls made. Biological data collected at sea are a useful supplement to sampling of commercial landings. In general, however, where possible most of these data should be derived from commercial landings, since these provide a much more constant and cheaper source of samples than research vessel surveys. It must be remembered however that commercial fishermen take a selected and biased sample of the population because of the gear they use and times and places they use it. Research vessel samples may be helpful to identify at least the second part of this bias and correct for it, though the gear selectivity is likely to be the same for both types of vessel.

3) Environmental data collection. This is a subject which is frequently given too much attention. Such data should only be collected if there is a clear indication that in this survey area, or other comparable areas, fish distribution is affected by an easily measurable hydrographic parameter. Such data should be collected only if the use to which it will be put is clearly defined.

In general, it is important not to "overload" the survey programme. One should not collect data unless one knows in advance what they are going to be used for. If the terms of reference of the project are of a rather general nature ("Survey of pelagic fish resources"), it may be useful to refine the objectives to one or two species, after some preliminary surveys. In small projects, care should be taken not to dissipate too much energy on a large variety of different species which require different survey strategies or fishing gears.

2.3 Area and Timing of the Survey

The survey area is generally indicated in broad outline in the terms of reference of the project. However, it is often advisable not to spread sampling effort evenly throughout the whole area, but to concentrate sampling in areas of high fish density (see section 2.6). Prior information on the distribution of fish may be obtained from reports of earlier surveys in the same area or in neighbouring waters. Local fishermen can sometimes provide information on typical fish distribution patterns and all sources of information on likely fish distribution should be used in designing the initial sampling scheme. If sufficient information cannot be obtained from existing sources, it may be worthwhile to make a preliminary survey in order to identify the most promising parts of the survey area. This initial sampling programme should subsequently be modified if necessary in the light of newly acquired data from survey results to increase the efficiency of future surveys.

Fishing surveys for resource appraisal are generally part of a special project, which may cover a period of a few months up to several years. If a certain amount of vessel time is available, one has to choose between making a small number of extensive surveys, or a larger number of more limited surveys. This choice depends on the expected distribution pattern of the fish. Fish with a fairly constant distribution pattern, but with large differences in abundance between various bottom types, need extensive surveys with a low frequency. On the other hand, some species, particularly pelagic ones, may show great differences in local abundance over short periods of time, due to seasonal migrations. In such cases, more frequent surveys are required, and the number of hauls per survey may have to be reduced. Indeed, if there is reason to suspect there might be significant year-to-year changes in distribution or abundance, it is essential to spread the survey work over several years. Otherwise a decision to invest or not to invest might be taken on the basis of what turned out to be an unusual year.

2.4 Precision and Accuracy of the Survey Estimate

The outcome of a resource survey may contain two types of errors: random and systematic ones. The random errors will be due to the variance between individual hauls. If the individual hauls have a high variance, the estimated mean number per haul will have a correspondingly high standard error. In that case, the estimate has a low precision. If the survey was carried out by identical ships over the same time period, we would probably arrive at considerably different mean values for each of these surveys. As we shall see later in this chapter, the precision of the survey can be improved by increasing the number of hauls and/or by concentrating the sampling in areas of high fish density (stratified sampling).

However, even with a very large number of hauls, and thus a high degree of precision, the survey estimate may still be quite different from the true value. In this case if the survey was repeated a number of times, the results would be very similar, but always different from the true value by the same amount. This is because a systematic error of bias is affecting the accuracy of the survey estimate. Systematic errors may result from such factors as a wrong type of sampling gear, from diurnal changes in the behaviour of the fish or from the common tendency of a ship's captain, if not controlled, to shoot his gear when he sees echo traces rather than at predetermined randomly selected positions. The catches then come from a density of fish that is higher than that for the survey area as a whole.

There is no way to measure the extent of systematic errors from the survey results themselves. All one can do is to try and avoid as far as possible systematic errors by making sure the gear is fishing properly and the distribution of the hauls is truly random. The accuracy of the survey results can only be checked by comparing them with stock estimates from a completely different source, e.g. acoustic or egg or larval surveys or tagging experiments.

The precision of the survey estimate on the other hand, can be calculated directly from the variance of the individual hauls. This will be treated in the next section. An estimate of the precision is very useful for administrators who are going to apply the results of the survey. If the precision of the survey estimate is below their minimum requirements this would demand an increase in the sampling intensity on subsequent surveys.

2.5 Confidence Limits of the Survey Estimate

In dealing with trawl surveys, the biologist often comes across statistical problems that may be new to him. Two examples of these are the following questions:

a) How precise is the survey estimate? For instance, if a survey of, say 50 hauls, in a certain area gives a mean catch of 500 fish per hour fishing how different is this likely to be from the true population mean (that is the mean of an infinite number of hauls in that area)? Or to put it in other words, what are the limits between which the true population mean will occur in, say 95% of all cases (95% confidence limits)? Will this be between 490 and 510, or between 300 and 800?

b) How many hauls should be made to obtain a predetermined level of precision? If one needs an estimate to be not more than, say 20% different from the true population mean, how many hauls should be made?

In order to solve these problems, we have to look at the statistical distribution of trawl catches, and more important, the distribution of the mean of a series of catches.

If a series of individual trawl catches is plotted in a size frequency distribution the result may look somewhat like Figure 1. This graph is quite different from the Normal or Poisson distributions that are usually found in biological data, in that it is very skewed with many hauls containing few fish while some hauls have exceptionally high numbers of fish. This is because of the tendency of fish to concentrate in special areas. These very skewed distributions frequently obtained from a series of trawl catches are examples of "contagious" distributions. They are characterised by a very large variance, greater than the population mean. A good description of the various types of contagious distributions is given by Elliot (1971). The statistic we are directly interested in, however, is the mean of the series of hauls. This has much simpler properties being normally distributed, regardless of the type of distribution from which the individual samples were drawn, provided that it is based on a sufficiently large number of observations (at least 30). Thus, if we repeated the survey a number of times using identical ships within the same time period, we would find that the mean values derived from each of these surveys would all belong to a normal distribution. The mean of this normal distribution is equal to the mean of the original skewed distributions and this is the value which we are trying to estimate from the results of the trawl survey.

The variance of the survey mean catch per haul $\bar{x}$ is

$$\text{var}(\bar{x}) = \frac{\text{var}(x)}{n}$$

in which var(x) is the variance of the original distribution of catch per haul x, and n is the number of hauls in the survey.

The standard error of the sample mean is

$$\text{standard error}(\bar{x}) = \sqrt{\text{var}(\bar{x})} = \sqrt{\frac{\text{var}(x)}{n}}$$

The fact that the sample mean is normally distributed, enables us to calculate its confidence limits which are:

$$\bar{x} \pm t \sqrt{\frac{\text{var}(x)}{n}}$$

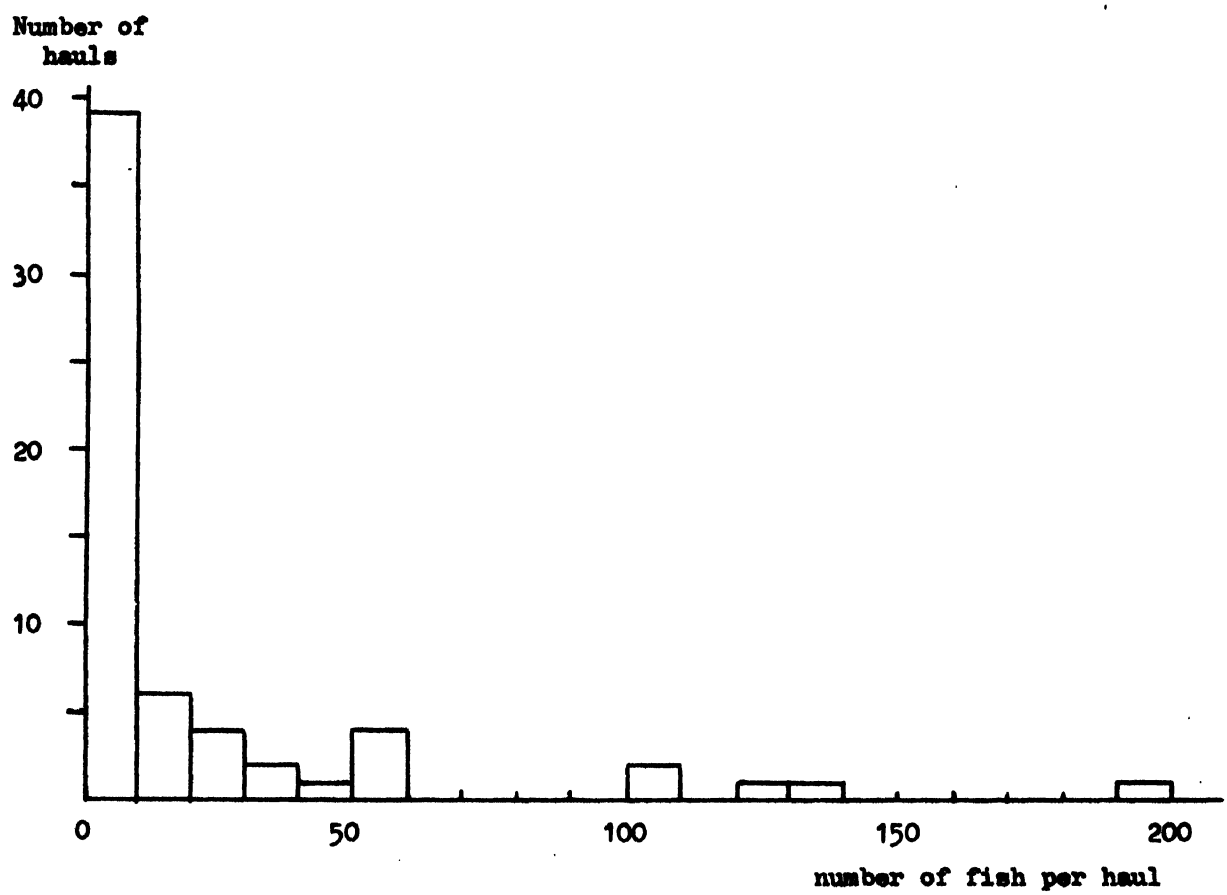

Figure 1. Typically skewed frequency distribution of trawl catches

The value of t (Student's value) can be read from standard statistical tables. The value to be used will depend on what % confidence limits are required and also on the degrees of freedom (number of hauls - 1). Some values of t are listed in Table 1. The standard error of the survey mean is dependent on the variance between individual hauls, and on the number of hauls in the survey. Increasing the number of hauls will result in a smaller standard error, and thus in greater precision. As the number of hauls increases, however, the gain in precision from a further increase will gradually decrease.

	t	
Degrees of Freedom (n^{-1})	90% Confidence Limits	95% Confidence Limits
30	1.70	2.04
40	1.68	2.02
60	1.67	2.00
120	1.66	1.98
∞	1.64	1.96

Table 1. Values of Student's t for various degrees of freedom

An example of the calculation of $\bar{x}$ and its confidence limits is given in Figure 2 and Table 2.

We have now seen that it is possible to calculate the degree of precision of a survey estimate, once the survey has been conducted and the results are available. In this situation we can also calculate what gain in precision would have resulted from an increase in the number of hauls. With this knowledge, sampling frequency for future surveys in the same area can be adjusted, assuming that the distribution of fish will be similar during these surveys to the one which has been completed.

If we have to design a survey in a completely new area, it is impossible to calculate in advance how much sampling will be required in order to obtain some predetermined level of precision. The best procedure in this case is to look at results of other surveys in comparable areas, and to calculate the relationship between sampling frequency and precision for those areas. Assuming that the variability in our own survey area will not be very different, this procedure gives a first indication of the amount of sampling required. By and large, it has been found in trawl surveys that the standard deviation of the catch per haul of a particular demersal species is about equal to the mean catch per haul, so as a rough rule it can be expected that the standard error of the estimated mean catch per haul will be:

$$\text{standard error } (\bar{x}) = \sqrt{\frac{\text{var}(x)}{n}} \qquad \bar{x}/\sqrt{n}$$

Thus if 100 hauls are made, the standard error of the estimated mean will be $\bar{x}/\sqrt{100} = \bar{x}/10$, or about 10% of the mean itself. For pelagic species the coefficient of variation of catches per haul (i.e. the ratio of the standard deviation and the mean) will usually be much higher, and the estimate of the mean consequently much less precise. Some trawl survey results are reported by Hennemuth (1976), and Jones and Pope (1973).

2.6 Stratified Sampling

A more practical and more efficient method of increasing the precision of the survey estimate is to divide the survey area into strata of more uniform fish density and estimate the mean and the variance for each stratum separately before combining them into overall estimates of the parameters for the survey area as a whole. Because the variance normally increases with the population density a further gain in precision can be obtained by concentrating more of the sampling effort in the higher density strata and allocating a lower proportion of it to strata where the density is expected to be low.

This procedure is called stratified sampling. Before the start of the survey, the area is divided into sections or "strata" of low and high fish density. Obviously this can only be done if we have some prior information on the distribution of the fish. This prior information may be derived from different sources:

a) topographical or hydrographical features which are known to be related to the distribution of fish density (bottom depth, type of sediment, salinity or temperature);
b) results of similar surveys in previous years;
c) results from a preliminary cruise made immediately prior to the main survey where no data of category a) or b) are available which can be used for stratification;
d) acoustic information from echo sounders. This method can be used when the echo sounder gives some indication of fish abundance, but when the acoustic information by itself is not sufficient to make quantitative estimates. In this case, the acoustic information is used to delimit areas of high and low fish density. Afterwards the actual density in each area is estimated by a number of trawl hauls (Doubleday, 1976).

Usually there will be no point in designing a sampling scheme with more than 2 or 3 strata, because our knowledge of the distribution of fish will be rather imprecise. Strata may be of different size, and each stratum may be composed of several distinct areas in different parts of the total survey area.

A demonstration of the benefits of stratified sampling is given in Figure 3 and Table 3. This example refers to the same area as Figure 2; the difference is that this time we know, from a preliminary survey, that the density of fish within the 20 m depth contour is eight times as great as in deeper water. The survey area has been divided into two strata: stratum A (less than 20 m depth) and stratum B (more than 20 m depth). The ratio between the area of stratum A and stratum B is 5:16. Sampling effort has been redistributed in such a way that stratum A has a sampling intensity (hauls per unit area) eight times as high as stratum B. The ratio between the total number of hauls in each stratum is found as follows:

surface area A:B = 5:16 — sampling intensity A:B = 8:1
(number of samples in stratum A): (Number of samples in stratum B)

$$= \frac{5}{16} \times \frac{8}{1} = \frac{40}{16}$$

If the total number of hauls is kept at 60, as in the previous example, there should be 43 hauls in stratum A and 17 hauls in stratum B.

Figure 3 gives the results that the survey might have yielded with this new sampling pattern. For each stratum, the mean, variance, and variance of the mean are calculated as in Table 3. These figures are then combined into one mean and variance for the whole area according to the following formulae:

Stratified mean (for the whole area):

$$\bar{x}_{st} = \frac{\bar{x}_a \cdot \text{area(A)} + \bar{x}_b \cdot \text{area(B)}}{\text{total area}}$$

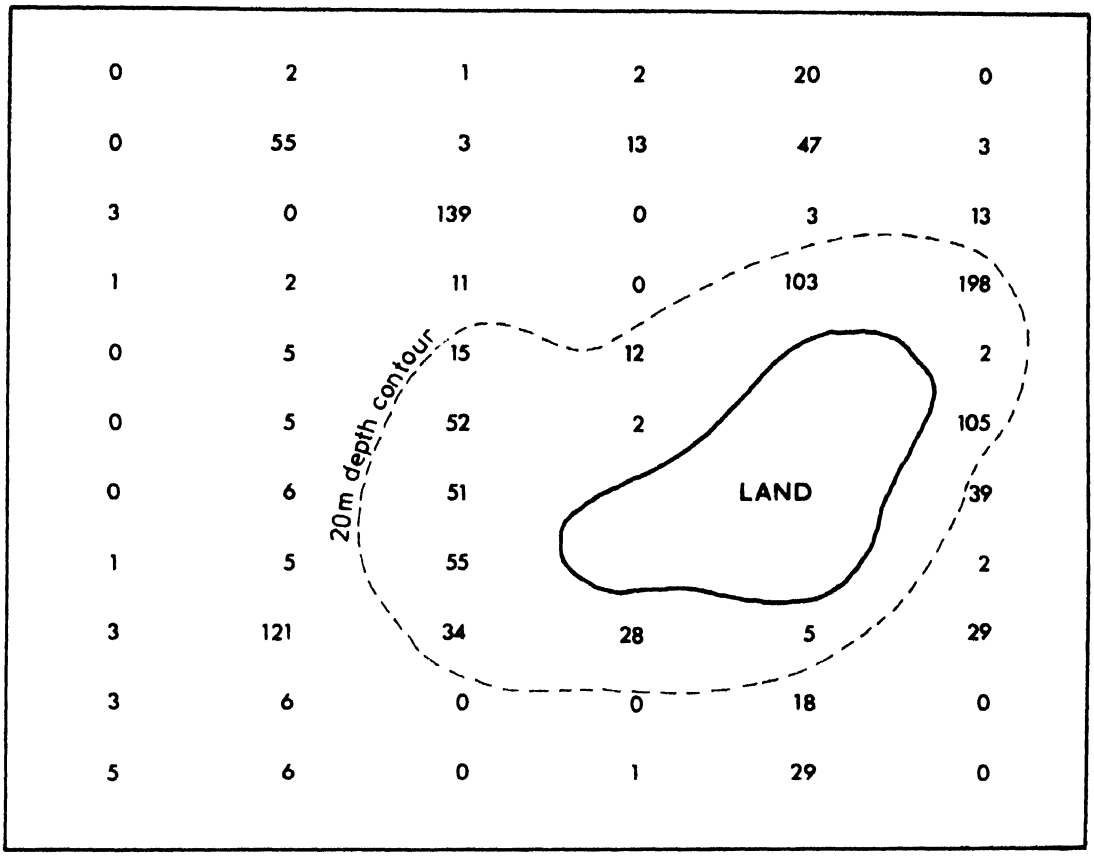

Figure 2. Results from a trawl survey with trawl stations spaced evenly throughout the survey area

Number of hauls = 60

Variance between individual hauls = 1,504.16

Mean number per haul ($\bar{x}$) = 21.07

Variance ($\bar{x}$) = $\frac{1,504.16}{60}$ = 25.07

Standard deviation ($\bar{x}$) = 5.01

Confidence limits ($\bar{x}$) ± t.(5.01)

90% Confidence limits ($\bar{x}$) = 21.07 ± (1.67)(5.01) = 21.07 ± 8.37 = 21.07 ± 39%

95% Confidence limits ($\bar{x}$) = 21.07 ± (2.00)(5.01) = 21.07 ± 10.02 = 21.07 ± 48%

Table 2. Calculation of mean number per haul and confidence limits for the data in Figure 2

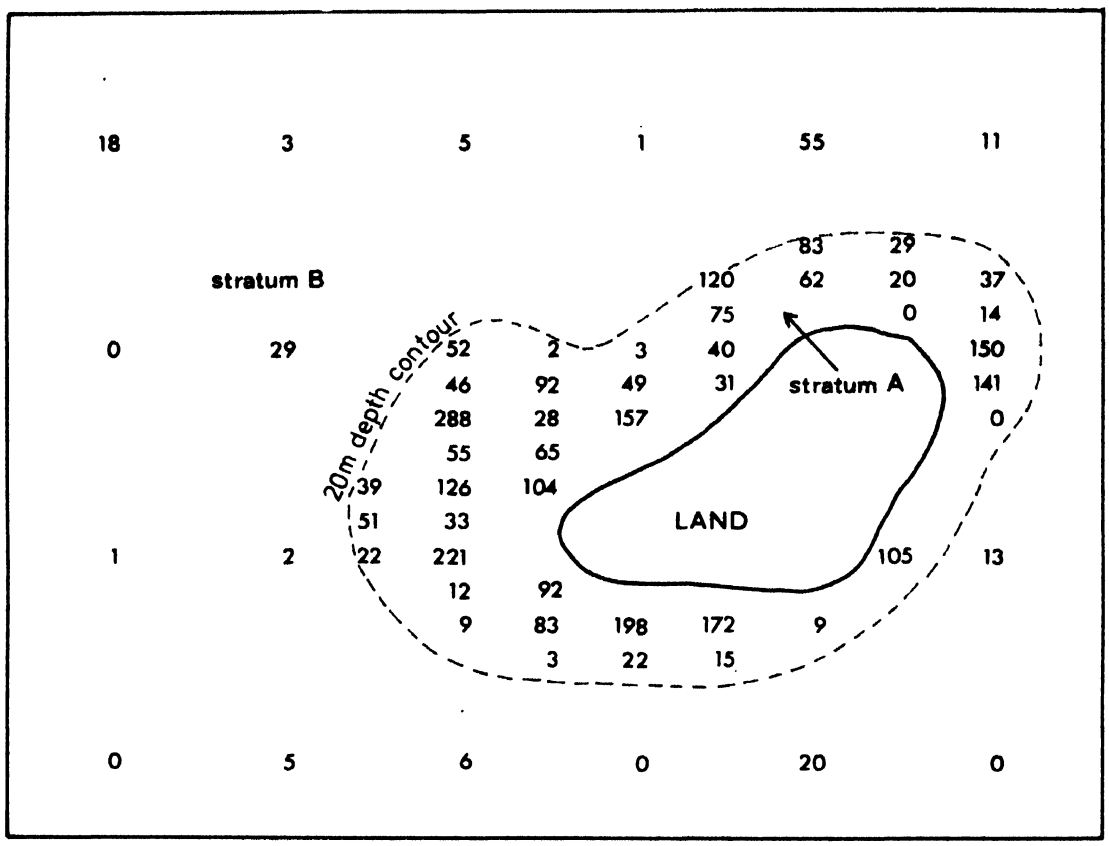

Figure 3. Results from a trawl survey with stratified sampling pattern. Stratum A (high sampling intensity) is defined by 20 m depth contour

	Stratum A	Stratum B
Number of hauls	43	17
Variance between individual hauls	4,385.21	206.31
Mean number per haul ($\bar{x}$)	68.72	9.94
Variance ($\bar{x}$)	101.98	12.14

Stratified mean = $\frac{5}{21} \cdot (68.72) + \frac{16}{21} \cdot (9.94) = 23.94$

Variance stratified mean = $\left(\frac{5}{21}\right)^2 \cdot (101.98) + \left(\frac{16}{21}\right)^2 \cdot (12.14) = 12.83$

Standard deviation stratified mean = 3.58

90% Confidence limits = 23.94 ± 5.98 = 23.94 ± 25%

95% Confidence limits = 23.94 ± 7.16 = 23.94 ± 30%

Table 3. Calculation of mean number per haul and confidence limits for the data in Figure 3

$$\text{variance } \bar{x}_{st} = \text{var } \bar{x}_a \cdot \left[\frac{\text{area(A)}}{\text{tot.area}}\right]^2 + \text{var } \bar{x}_b \cdot \left[\frac{\text{area(B)}}{\text{tot.area}}\right]^2$$

in which $\bar{x}_a$ and $\bar{x}_b$ are the mean numbers per haul for strata A and B respectively.

In situations with more than 2 strata the general formulae will apply:

$$\bar{x}_{st} = \sum \frac{\bar{x}_n \cdot \text{area(N)}}{\text{total area}}$$

$$\text{var } \bar{x}_{st} = \sum \text{var } \bar{x}_n \left[\frac{\text{area(N)}}{\text{tot.area}}\right]^2$$

For the data in Table 3 we find a stratified mean of 23.94, and 95% confidence limits of ±7.16.

It is evident that the 95% confidence limits, expressed as a percentage of the mean, have been reduced by the stratified sampling procedure (from 48% to 30%). For the same amount of sampling effort, our results have become more precise, or in other words, we have got better value for our money.

2.7 Sampling Gear and Methods

2.7.1 Type of net

The type of gear will depend on the type of fish we wish to catch. Most frequently the choice will be for some type of bottom trawl. In some cases, trawls cannot be used for resource appraisal surveys, and other gears such as purse-seines, gillnets, handlines, traps etc. have to be utilized. For such gears estimates of absolute population size are much more difficult to derive and the problem of making such estimates with an acceptable degree of precision has not yet been solved for any of these gears. In the case of purse-seines and midwater trawls the problem arises from the fact that the pelagic species for which these gears are appropriate have generally a very high contagious distribution and fishing for them at randomly selected positions is not likely to be productive. For these pelagic species acoustic surveys (see Chapter 3) are probably the most effective way of obtaining absolute stock size estimates. Fishing is used primarily to identify the species which are contributing to the returned echoes and to provide samples to measure their biological parameters.

For gears such as gillnets, hook-and-line, traps etc. the problem lies in assessing the area from which the catch taken by them is derived and their catchability coefficient for the fish within that area. These gears however can provide measures of relative abundance, between sub-areas or between time periods, for the species to which they are appropriate. We shall therefore concentrate on trawls in the rest of this chapter. Most of the advice on sampling methods and standardization will apply equally to other gears.

In choosing a sampling gear, the following requirements should be kept in mind:

The gear should be simple to operate and to repair. Generally, an exploratory fishing survey will be made only occassionally, say once a year. If the gear used for this survey is too complicated, the crew will not have sufficient opportunity to get familiar with the net in the limited time available. Particularly when several ships, or even countries, participate in the survey, it is important to keep the gear as simple as possible. There is no point in choosing the biggest and most modern gear available: the objective of the survey is not to make record catches, but to make as many comparable hauls as possible without too many technical interruptions. (Note: this is an important difference from experimental fishing or prospecting surveys where the objective is to assess the maximum catch rates that can be obtained with the gears that will be used commercially).

There is an advantage in choosing a gear which has been used commercially. Such a net will be free from the initial faults of a newly-designed net, and it will be easier to obtain spare parts or a replacement for the net.

The gear should be suitable for use on a range of bottom types. In a survey it is not always possible to select the best trawling grounds, because trawling positions have to be chosen at random. Gear damage is likely therefore to be more frequent than in commercial trawling. In order to avoid excessive loss of time due to gear damage, a rather sturdy fishing gear should be used.

The gear should be adapted to the type of fish we are mainly interested in. Even amongst bottom trawls, there are large variations in size, vertical opening, mesh size, tickler chains etc. For each species of fish, the commercial fishermen will tend to use a special trawl and a special rigging. Small alterations to the net or its rigging may greatly influence its catching capacity for certain species. Even for closely related species, the availability to the gear may be very different. The experience of local fishermen can be a useful source of information in this respect. Also, it will be very useful to test different types of rigging before the start of the actual survey.

2.7.2 Standardization of sampling gear

This is a subject of great importance. A fishing gear is such a complicated sampling instrument that there are hardly ever two nets which fish in exactly the same way. The catching power of the net depends on its construction and rigging, the fishing method, the size of the ship, and finally on the experience and skill of the crew. Obviously, the problems of standardization are greatly increased if one is dealing with more than one ship. The factors "ship size" and "experience of the crew" are hard to standardize. Although complete standardization can perhaps never be obtained, it is absolutely necessary to use identical nets, rigging and fishing methods throughout a survey and on subsequent surveys.

Once a suitable net, rigging, and fishing method have been chosen, these should be described in complete detail in the survey programme and report. An example of the specifications to be given is found in Table 4.

Preferably, no alterations should be made to the method or gear during future surveys in the same area, even if the possibility of technical improvements becomes available. It is much better to carry on with the traditional gear and relatively low catches, than to change the method and be faced with all the problems of calculating conversion factors for the old data.

2.7.3 Comparative fishing

Sometimes, however, it may be unavoidable to change sampling gear or method after a number of surveys, because of changed survey objectives. In such cases, a comparison has to be made between the fishing power of the new and old gear. Comparative fishing should also be done when two ships, participating in the same survey, for some reason cannot use identical sampling gears. Obtaining reliable conversion factors from one gear to another is a very tedious job. The within-haul variance for each gear is so high that it takes a large number of hauls to obtain a precise estimate of the ratio between their fishing powers.

The most practical method is to make paired hauls with both gears, and to compare catches between the two hauls of each pair. Making paired hauls can be done with two research vessels fishing side by side, or by one ship using both gears alternately. The former method by allowing the two nets to be fished closer and more readily on the same patch of fish, usually has less variance and is to be preferred when possible. A total of at least 20 pairs will be necessary to get any meaningful conversion factor.

Table 4. Description of fishing gear and method

Fishing Gear	1.	Construction of the net, including number of meshes per section, mesh size, twine thickness, twine material. This information is normally given in a technical drawing.
	2.	Bridles: length, diameter, material.
	3.	Headrope: length, diameter, material.
	4.	Footrope: length, diameter, material, division in sections, extra weight (chain), how distributed.
	5.	Roller gear or false footrope (if applicable): detailed description or technical drawing.
	6.	Floats: number, volume, material, where attached.
	7.	Kites: number, size, thickness, material, how and where attached.
	8.	Trawl doors: size, weight, material, shape.
Fishing Method	1.	Fishing speed.
	2.	Ratio of warp: depth. This ratio will depend on the depth of the bottom and also on the bottom substrate.
	3.	In which areas to use roller gear or false footropes.
	4.	Duration of haul.
	5.	Period of the day when fishing should be conducted.
	6.	Direction of tow in relation to tidal currents.

A comparative fishing experiment may be conducted as part of the actual survey. If several vessels participate in a survey, it is useful to plan a comparative fishing experiment as part of the programme, in order to investigate possible inter-ship differences.

2.7.4 Position of trawl stations

Trawl stations must be randomly distributed within the survey area, or within the strata, to avoid biased results. Two well-known examples of non-random distribution of sampling, giving rise to systematic errors are:

a) The skipper, if not given precise instructions, is inclined to select the most suitable grounds for bottom trawling. This will result in an underestimate of the abundance of species which are distributed mainly on rocky grounds and conversely an overestimate of those distributed on sandy or muddy ground.

b) The skipper is inclined to select those grounds that he knows from experience or from echo-information will contain most fish. This procedure leads to an overestimate of the abundance.

Apart from avoiding these two obvious sources of bias which will result in major overestimation of the true fish abundance, it is also necessary to avoid less easily detected bias which can result from non-random selection of fishing positions. In fact, if the fishing positions are arranged on a square or rectangular grid pattern with the stations at fixed distances apart, although the station positions have not been randomly selected in the strict sense they will almost certainly be randomly positioned in relation to the distribution of the fish. This procedure has the benefits that fishing operations are carried out in a more regular time pattern, which is more convenient for the scientists and crew, and is less likely to result in wrong recording of fishing positions on data sheets. If it is considered desirable to avoid the minor risk of bias which could result from this procedure the strata can be divided, by a grid, into small equal sub-areas, which should be of a size about four times the square of the accuracy of navigation. These areas can then be numbered and the ones to be sampled chosen from a table of random numbers - the number of areas to be chosen within each stratum being estimated as described in section 2.6.

When making a survey in a new area, it is advisable to first explore each trawling position by echo sounder before shooting the gear. A trial run can be made using only the echo sounder and, if the bottom is reasonably smooth for the trawl to be used, the same track can be fished with the trawl. If this is not so, a fishable track should be sought in the vicinity using the same technique, and when located substituted for the trawling position which had to be rejected.

On subsequent surveys the stratification design may need some modification in the light of the results of the preceding survey; if not the same fishing positions should be used in all subsequent surveys. If, despite the precautions described in the previous paragraph, gear damage is sustained another trawl track, within the same sub-area, should be selected and the trawl-haul repeated there. If the trawl comes fast, and has to be hauled, but without serious damage after only a short time fishing the catch should be rejected and the haul repeated as described above. If the net has been fishing for half or more of the standard towing time the catch can be accepted and the results multiplied by the appropriate factor to make them comparable with hauls of standard duration.

2.7.5 Time and duration of hauls

For several species of fish, there are marked differences in catchability between day and night. If a survey is to be conducted during 24 hours of the day, it is advisable to investigate the difference in catch rates between day and night before the start of the survey. This should be done by making a large number of hauls (say at least 40) in the same position during several 24 hour cycles. On smaller vessels it will not be practical to work

both day and night. In that case, fishing will normally be conducted during daytime, and it should be clearly defined which hours are counted as daylight period. If the resulting data are to be used only for comparative monitoring purposes then it is only necessary to correct any hauls taken during daylight to night values using the factor obtained as described above. If the data are to be used for absolute abundance estimates then they should be corrected for the time of day to which the catchability coefficient applies (see section 6.3).

The duration of the haul is measured from the moment the trawl has settled on the bottom (the brakes are put on the winch) until the winch starts hauling again. There has been much discussion in the past on the optimal duration of the hauls. In general, one has to choose between a smaller number of long hauls or a larger number of short hauls. Making short hauls means that more time is lost in hauling and shooting the gear, and less time can be spent actually fishing. However, in view of the large within-haul variance, it is advisable to increase the number of hauls as far as possible. This will give an increase in the precision of the survey results (paragraph 2.5). A duration of 30 minutes per haul is sufficient for most purposes. Short hauls have the added advantage that gear damage is more quickly discovered and repaired.

2.8 Sampling the Catch

Sampling the catch is a matter of using time and manpower as economically as possible. Each haul should be sorted, the quantities recorded, and any biological samples collected before the next one comes on deck. Normally, fishing operations should not be interrupted by sampling activities. Research vessel time is much too costly to have the ship floating around idly, while biologists are dealing with the catch from a previous haul. The main objective of the survey is to estimate the abundance of a few commercially important species. The abundance of these species in the catch can normally be estimated adequately in the time interval between two hauls. The attention given to other species of lesser importance should depend on the amount of surplus time available after the important species have been sorted and until the next catch comes on board. Care should be taken not to spend valuable vessel time in measuring large quantities of non-commercial species.

Estimating the total catch can be conveniently done by sorting it by species into baskets of uniform size and counting the number of them. If there is a wide range of size within a species it is preferable to sort that species into size groups in separate baskets and count the number of baskets in each size group. If time does not allow sorting by species the catch can be sorted by size, without species separation, and a small number of baskets taken as a subsample from each size category, after counting the total number of baskets of each size category in the catch.

Selecting the fish to be used as a subsample for getting the species composition of the unsorted part of a catch, or for measurement of the size composition of a catch which has been sorted by species, should be done in a way which ensures that the subsample contains a random selection of the catch. The first step is to decide the number of baskets which can conveniently be worked up. This number of empty baskets should then be laid out and filled by distributing equal proportions, from each basket of that category in the total catch, to fill these empty baskets - e.g. if the total catch is 20 baskets and it has been decided that 4 baskets can be sampled then a fifth of each basket in the catch should be tipped, in random order, into each of the 4 empty baskets. If this first-stage subsample still contains too many fish of some categories for sorting and measuring the baskets are redistributed by the same procedure.

If some very large fish (e.g. shark) occur in the catch, these are taken out of the catch and recorded individually, before the subsamples are taken.

Species of special importance are sorted out in an early stage of the subsampling procedure. For instance, if the survey is intended for herring, we should try to sort all herring from the total catch or at least from the first stage subsample. Species of less importance should only be sorted at the second or third stage in the subsampling. If a species occurs in two clearly distinct size categories, the large individuals could be

selected from the whole catch or the first subsample, and the smaller individuals from the second or third stage subsample. Whenever, possible, the crew should be called upon for assistance in sorting the catch. The ultimate aim of this procedure is to get a measure of the total weight of the catch and of each species within it. Because of the difficulties of weighing accurately at sea it is more convenient as a routine procedure to measure the catch in terms of volume (standard baskets). However to subsequently convert these to weights the first convenient opportunity should be taken to weigh some baskets of each species, mixed species, or of size categories so as to get appropriate conversion factors from volume to weight. It should also be remembered that there may be seasonal variations in the volume to weight conversion factors.

For each species in the catch, or each size group sorted within a species, the total number of fish contained within the subsample selected should be measured and counted (see section 5.6 for more detailed information on recording procedures). Other biological information, such as age, maturity stage, sex etc. can frequently only be ontained from a more limited number of individuals within the subsample. As many of these characters are related to length the most efficient estimate of the frequency of these characterisitcs within the catch can be obtained by taking length stratified subsamples; e.g. five fish within each length grouping. Fuller advice on subsampling procedures on board research vessels will be found in Holden and Raitt (1974) and on subsequent treatment of stratified sampling in Chapter 5 of this manual.

2.9 Cruise Programme and Report

It is always necessary to make a detailed cruise programme before the ship goes to sea. Once the ship is at sea, often in unfavourable weather conditions, people on board (including the chief scientist) often lose their ability to make intelligent plans. The enthusiasm which they felt in the laboratory may quickly disappear at sea. The only thing that keeps them going under those circumstances is a clear and detailed set of instructions. A set of preprinted forms which clearly define what data are to be collected and recorded is also of help in this context (Chapter 5).

A cruise programme should contain a detailed description of the work to be done and the methods to be used. If working methods have been standardised, the same set of instructions can be used for subsequent surveys. It is important to indicate alternative programmes to be carried out in case of gear loss or unsuitable weather conditions. A sufficient amount of spare time should be included in the programme, in view of unexpected problems that may arise during the cruise (bad weather, gear damage, engine trouble etc.). Depending on the local conditions, this may require an additional 20-30% vessel time above the minimum amount that would be needed under optimal conditions. In drawing up the plans, it is useful to indicate the priority of the various experiments or areas to be worked. This will help to ensure that the most important work is done in case part of the time is lost. The cruise programme should also contain a list of materials and equipment which will be required during the survey. This may be a standard list if the cruise is a routine survey. Of course the complete list should be checked before the vessel sets out on the survey.

During the cruise, it is a useful practice to keep a scientist's log. Just like the skipper and the engineer, the scientist in charge should keep a daily record of his main activities on board. The scientist's log should contain a general review of the number of stations finished, loss of time due to various causes, any decisions that were taken to alter the cruise programme, damage or loss of equipment, remarks concerning the improvement of equipment or methods etc.

Such a logbook will greatly facilitate the writing of a cruise report after the survey. Apart from the scientists' log, of course the normal record forms have to be completed for every trawl station or hydrographic station.

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3. ACOUSTIC SURVEYS

Acoustic techniques are an important tool at the disposal of those concerned with fishery resource appraisal. Like the methods described in Chapters 2 and 4 (exploratory fishing and indirect methods) acoustic techniques are independent of catch statistics. They can be used to assess exploitable stocks which have not yet been fished and therefore can provide estimates of stock size prior to a fishery. In addition, acoustic techniques provide the capability to survey a resource much more rapidly than can be done by exploratory fishing. However, acoustic techniques do not provide species composition, or other biological information, nor are they suitable for most demersal stocks. Thus, they are best employed in conjunction with exploratory fishing.

3.1 Characteristics of Acoustic Systems

About 1930, it was discovered that the ultrasonic depth sounder could also be used to detect fish, and subsequently it became widely used for fish detection and quantification. Although special research echo sounders and sonars and several types of automatic signal processing systems have been developed for fisheries investigations, the basic part of most systems for acoustic surveys is still a standard depth sounder or a sonar (horizontally ranging echo sounder), and analysis of echograms is still probably the most widely used technique in assessing survey results.

A sonar or echo sounding system basically consists of four parts: (1) control and display, (2) transmitter, (3) transducer, and (4) receiver-amplifier. The display is generally a paper recorder, but it may be an oscilloscope or cathode ray tube (CRT).

The transmitter provides the electrical energy which is converted to acoustic energy and propagated through the water by the transducer. In most systems the same transducer receives the returned echoes, converting them back into an electrical signal. The receiver-amplifier increases and modifies the signal to a level and form suitable for display.

Paper recorders for echo sounders come in a variety of types and sizes. They have two basic functions: (1) to trigger the transmitter; and (2) to record the echoes as a function of depth. The number of transmissions per unit time is called the pulse repetition rate. It is governed primarily by the range to be displayed and the depth of the bottom. Echoes generated by the previous pulse must return before a new pulse is transmitted or there will be confusion as to the true depth of the echoes, for example, a false bottom (Edgell 1935). The depth range displayed on the recorder depends on the speed of the rotation of the stylus and on most recorders this can be controlled to give appropriate depth ranges. For a given paper width, the faster the stylus, the smaller the range displayed (or the greater the range resolution). Echograms do not give appreciable information on the size of targets, but are primarily presence or absence indicators. The amplitude can be displayed on a CRT, but this provides no permanent record.

Each time the transmitter is triggered by mechanical contact or a trigger pulse from an electronic circuit, it produces a pulse of electrical energy of a certain width, frequency and power. The maximum range of an echo sounder is dependent on the power, and on some additional parameters. There is an upper limit to the amount of power which can be applied to a transducer of a given size. The range resolution of the echo sounder is dependent on the pulse length (i.e. the duration of the transmitted sound pulses) - the smaller the pulse length the greater the resolution. In typical echo sounders pulse lengths range from 0.1 to 50 m/sec. with frequencies typically in the range of 20 to 200 kHz.

The electrical energy from the transmitter is converted into a pulse of acoustic energy by the transducer. This is accomplished by small vibrations which displace the particles of the water back and forth, resulting in pressure changes. Similarly, pressure changes associated with the reflected sound wave are detected by the transducer when the echo returns and converted into electrical energy.

The beam of sound transmitted by an echo sounder is often visualized as a cone, but in reality it is much more complex. Transducers concentrate or direct sound in a particular direction. The transducer face can be regarded as consisting of many point sources which interact so that the sound intensity varies with direction, and is at its maximum in a direction perpendicular to the transducer surface (where all waves are in phase) called the acoustic axis. Both the power transmitted and the receiving sensitivity decrease with increasing angle from the acoustic axis. This variation is described by the directivity pattern function, $b(\theta, \phi)$, which simply represents the distribution of transmitted power or receiving sensitivity at any angles θ (from the acoustic axis) and ϕ (in the plane of the transducer) compared with that on the acoustic axis. An example of the transducer directivity as a function of the angle θ is shown in Figure 4. For a circular transducer, the directivity pattern would be the same for all values of ϕ.

The width of the beam is often defined by the angle where the intensity has decreased to one-half (-3dB) of the value on the acoustic axis. The width depends on the size of the transducer in relation to the frequency. Larger transducers and higher frequencies result in narrower beams (that is, the energy is more concentrated along the acoustic axis).

The amplitudes of the echoes are very small compared to the power transmitted. The primary function of the receiver-amplifier is to apply the appropriate amplification to the signals received by the transducer.

Almost all receivers have a manual gain control which increases or decreases the overall amplification of the receiver. Most also have some type of time or depth dependent gain function which is important for both display and quantitative processing since the signal levels decrease with range. This feature may be merely an initial suppression circuit to eliminate or decrease the signal levels from near surface targets, especially those due to non-biological factors such as turbulence from surface waves, or it may be a time-varying gain (TVG) which compensates for spreading and attenuation losses.

Most receivers also include a feature to delineate the bottom. This feature (often called a "white line") converts the bottom echo to a thin line on the display by blanking out signals for a fixed time after receipt of the large bottom echo.

3.2 Some Basic Principles

Acoustic techniques are based on the fact that the amount of sound reflected from fish targets is a function of their abundance. The speed of sound propagation through water varies with temperature, salinity and depth, but is usually between 1,400 and 1,500 m/sec. As sound propagates, the sound intensity, that is, the energy per unit area in the sound wave, decreases because of geometric spreading and absorption. Thus, the sound intensity (I_r) at some range (R) can be described by the relationship:

$$I_r = \frac{I_1 \, 10^{-\alpha R}}{R^2} \qquad \ldots\ldots 1$$

where I_1 is the intensity at a unit range from the transducer (sound source), and α is the attenuation coefficient, which is a function of the sound frequency and the water temperature and salinity.

When sound strikes a target, the intensity of the reflected sound is proportional to the intensity of the incident sound, that is

$$I_r = kI_i$$

where I_r is the reflected sound intensity a unit distance from the target, I_i is the incident sound intensity, and k is a constant dependent upon the reflective properties of the target.

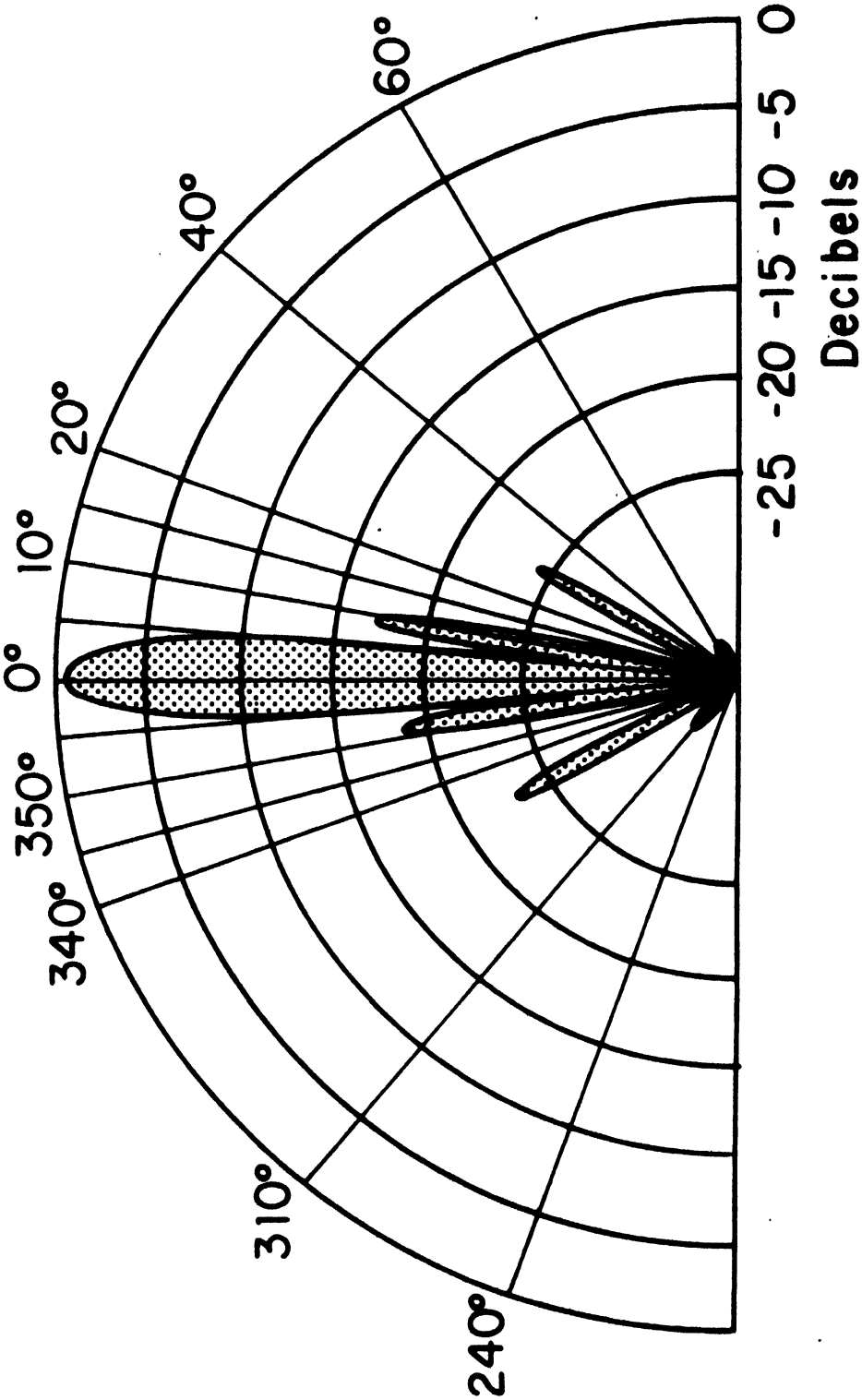

Figure 4. Example of a transducer directivity pattern

As the reflected sound returns to the transducer, it is further reduced by geometric spreading and absorption. The generalized expression for the echo intensity I_e measured at the transducer is therefore:

$$I_e = \frac{kI_1 \, 10^{-2\alpha R} \, b^2 (\theta, \phi)}{R^4} \qquad \ldots\ldots 3$$

where $b^2 (\theta, \phi)$ is a factor for the transducer directivity pattern and the other symbols are as defined above in relation to equations 1 and 2. The factor for transducer directivity is equal to 1.0 on the acoustic axis and to less than 1.0 at all other angles. Equation 3 is often expressed in decibel units, which measure ten times the ratio of intensities in logarithmic units, i.e.

$$10 \log_{10} \, (I_e/I_1)$$

In decibel (dB) units, the sonar equation is:

$$EL = SL + TS - 40 \log R - 2 R + 20 \log b (\theta, \phi)$$

where EL is the echo level, SL is the source level ($10 \log I_1$), and TS is the target strength ($10 \log k$).

The target strength depends on the size of target and on its reflective characteristics. The target strength of fish is generally a function of size (Figure 5), but also varies between species (especially between those with and without a swim bladder) and is very dependent upon the aspect (orientation) of the fish.

3.3 Methods of Abundance Estimation

There are basically two types of acoustic data processing: (1) counting and (2) amplitude measuring. Counting techniques depend on resolving and enumerating individual targets. Amplitude measuring techniques are based on the principle that the reflected sound intensity (amplitude-squared) is, for a given size and species of fish, directly proportional to the fish abundance (assuming appropriate range corrections are made). The proportionality constant includes the acoustic system parameters and the mean fish target strength. Within these two basic types, the analysis technique may utilize echograms, oscilloscopes, or more sophisticated, automatic signal processing equipment.

3.3.1 Analysis of echograms

The easiest and most widely used acoustic methods of abundance estimation are based on echogram analysis. Considerable information on the abundance and distribution of fish stocks can be obtained by these techniques even though much of the signal amplitude information is lost on the paper record. It is important, however, to understand the limitations and sources of error in echogram analysis techniques.

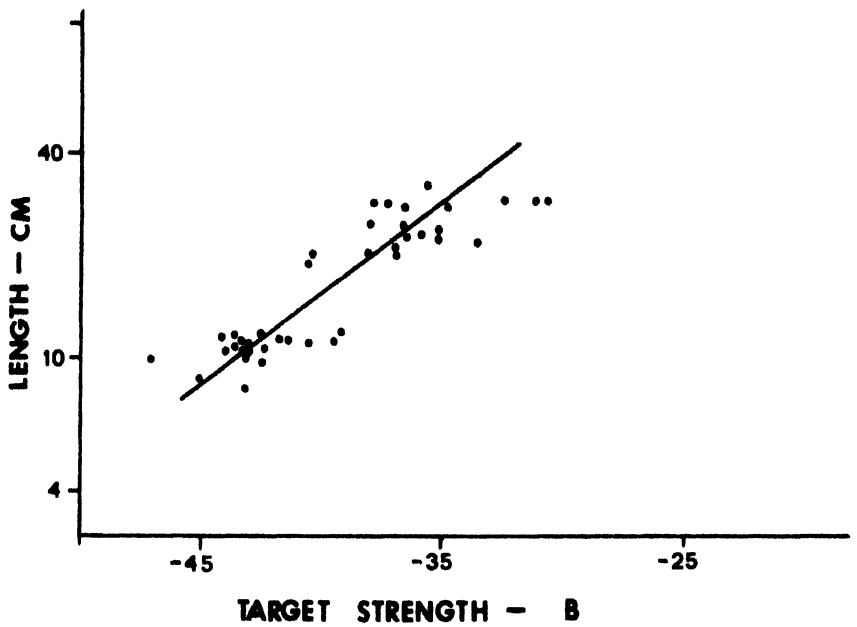

Figure 5. Observations of the maximum target strength of herring at 120 kHz as a function of length of fish (from Nakken and Olsen 1973)

3.3.1.1 Echo counting

When fish densities are low or near-surface, the targets recorded on the echogram may be predominantly individual fish. In that case a relative measure of abundance can be obtained by merely counting the number of traces per unit distance. Caution must be exercised since the volume sampled is not only a function of depth, but is also dependent upon the interrelationships between depth, fish target strengths, and the overall gain and time-varied-gain characteristics of the echo sounder. These problems are greatly duced if the echo sounder has a good TVG. The appropriate depth correction for echo counting is 40 log R + 2αR and in equipment with this facility this correction is made automatically by the TVG.

Rough estimates of absolute abundance can also be derived from echo counts in circumstances by inferring the size of the sampled area from the lengths of echo traces on the paper recorder. Suppose that all the fish detected lie in a thin layer at an unknown depth. If the beam is circular, the area scanned at this depth will also be circular. As the ship passes over a single fish, which can be regarded as a stationary point target, the fish will be recorded over the length of some path across the circular beam field parallel to the

ship's course. If the fish is directly under the ship, the length of this path will be the diameter of the beam field, but if the fish is off to one side of the ship, the path will be a chord shorter than the diameter, and at the extreme edge of the field perpendicular to the ship's course, the path will be only a point.

On the assumption that fish will be distributed randomly with respect to the ship's course, it can be shown that the mean path length $\bar{P}$ of a single fish across a circular field of diameter D will be:

$$\bar{P} = \frac{\pi D}{4}$$

Hence the diameter of the field $D = 4\bar{P}/\pi$ can be calculated from the mean path length $\bar{P}$, which in turn can be calculated from the mean length $\bar{p}$ of echo traces on the recorder, since

$$\bar{p}/\bar{P} = s/S$$

where s is the speed at which the paper advances on the recorder and S is the speed of the ship.

The area scanned by the beam during a given interval of time can be calculated directly as the product of the estimated beam diameter D and the ship's speed S, and this swept area, in conjunction with the count of echo traces recorded during the time interval, will provide an absolute estimate of density (number of fish per unit area).

In practice, this method encounters various complications. Clearly the actual value of $\bar{P}$ will depend on the transducer's directivity pattern $b(\theta, \phi)$, the target strength of the fish, and on the level of the threshold between detectable and undetectable echoes. In general, there will be a proportion of fish whose target strengths will be too low for them to be detected. Thus any estimates will be biased in favour of larger fish and if the sounder does not have the correct TVG this bias will increase with depth. Moreover, the relationship between mean trace length and swept area is more complicated in the case of elliptical and rectangular beams than in the case of circular beams. Still, most of these factors can be taken into account in the analysis one way or another.

3.3.1.2 Visual grading

This technique is a system of assigning relative density values to a portion of the echogram on the basis of the degree of blackening of the paper record. A simple scale described in Forbes and Nakken (1972) categorizes densities on the echograms into four grades: (1) very scattered just colouring the paper, (2) scattered-between black and white, (3) dense-black, and (4) very dense-activating the white lines. The technique is best used in combined acoustic-exploratory fishing surveys, since results of fishing can provide the required information on the relative abundance associated with the different grades.

A four-category grading system has the advantage of simplicity and relatively low subjectivity. However, it suffers from a lack of precision since only four values are assignable to natural densities which may range from less than one fish per 10,000 m^3 to more than 100 fish per m^3. More complex grading schemes can be developed and, depending on the individual's skill and experience, can be surprisingly accurate. The results of an experiment conducted at the FAO/NORAD Training Course in Acoustic Methods for Fish Detection and Abundance Estimation in Cochin, India, during November 1973 can be used as an example (Figure 6). Students were asked to examine various sections of echograms and assign relative density values. The correlation coefficient between the students' visual grading results and the actual Simrad QM echo integrator measurements of relative density was greater than 0.9.

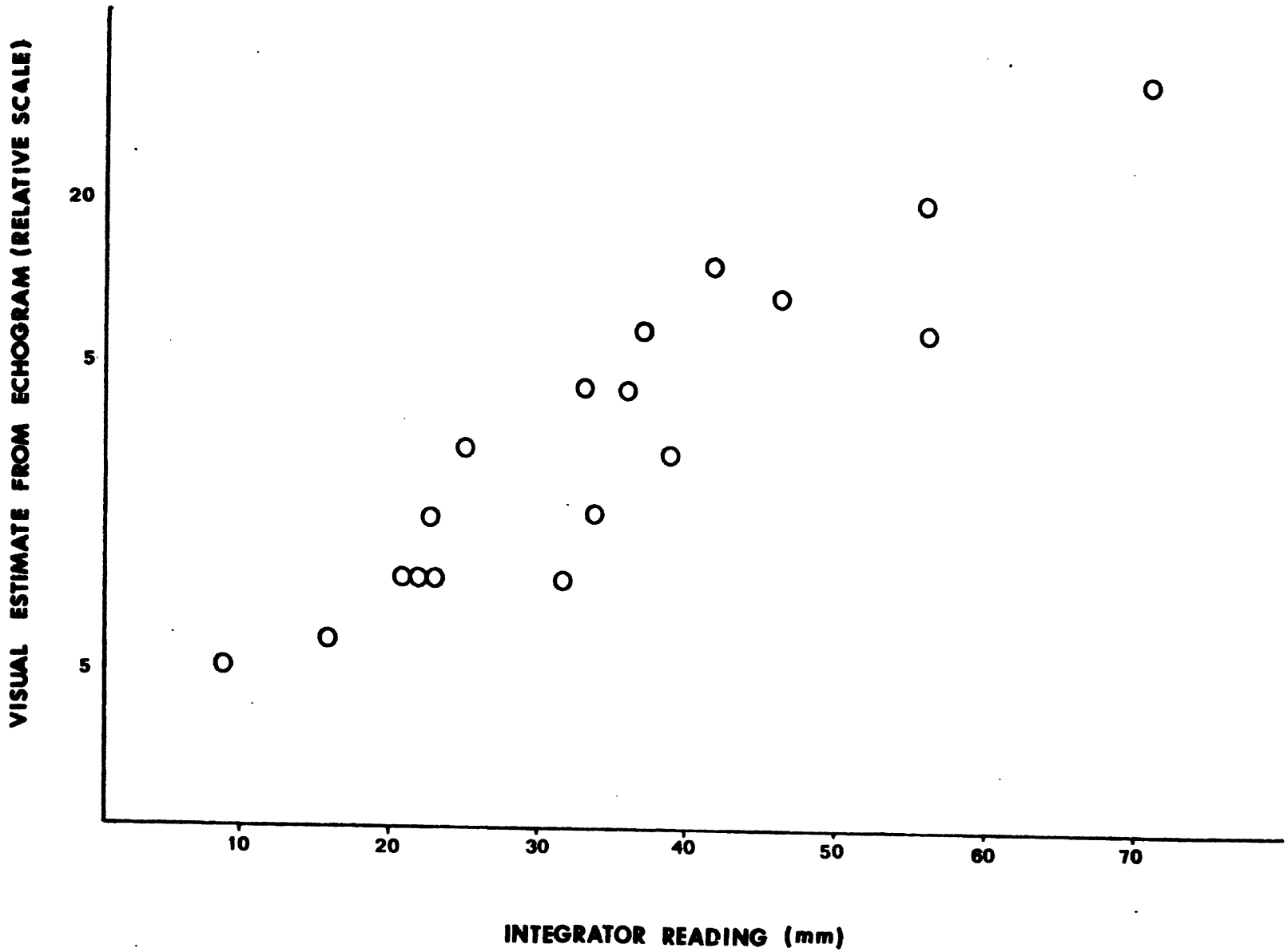

Figure 6. Comparison of visual estimates from an echogram and corresponding measurements of integrated echo intensity

One of the major problems with the visual grading technique is that it is greatly affected by the condition and characteristics of the echo sounder. The example in Figure 7 shows that a grade 2 trace can be changed to grade 4 by changing the echo sounder gain and "white line" settings. Similar effects occur if the performance of the echo sounder changes with time. Also, traces at different depths, or different kinds of traces, i.e. layers versus schools, are difficult to compare. It should also be noted that in the case of multiple echoes, the appropriate TVG correction is 20 log R + 2αR.

3.3.1.3 Counting and sizing of schools

A simple count of schools encountered per unit distance steamed provides a measure of relative abundance. The measure can be improved by taking into account the size of schools. It is difficult to determine the true size of schools from a single crossing, since they are often irregular in shape and there are an infinite number of possible paths over them. However, an unbiased measure of the relative abundance of fish in schools can be determined by measuring the relative proportions of transects occupied by schools. For example, if 10% of the distance steamed along a transect was spent over schools, then it may be inferred that, regardless of individual school shapes and sizes, 10% of the total survey area is occupied by schools. The relative volumes occupied by schools in successive surveys can be determined by summing the products of the observed mean vertical thicknesses of schools and the corresponding transect proportions.

The technique of school counting and sizing is especially useful for sonar operations on near-surface pelagic schools, which may be difficult to survey with conventional downward-looking systems. For sonar systems, the horizontal dimensions can be readily measured, but the vertical extent cannot (Smith, 1970). Sonar techniques of school counting and sizing have been used routinely for surveys of anchovy off California and Mexico (Hewitt et al., 1976).

There are still several technical problems to be solved before these school counts and size frequencies can be converted into absolute estimates of stock biomass, and the techniques and equipment used in these surveys are too sophisticated to be readily available to most resource survey projects. However, sonar, as a means of detecting and estimating the frequency of and size of schools, has obvious advantages over vertical echo sounding in the case of near-surface pelagic schools which are not available to the latter because they are above the transducer depth. It may also have an advantage where there is evidence that schools of pelagic fish move out of the path of an approaching ship because of disturbance by engine noise or propeller reverberation.

A rough assessment of stock biomass in such cases might be obtained by a sonar survey to count schools and estimate their size frequency distribution. These could then be converted to school biomass and species composition by purse-seine fishing directed at schools of the size ranges detected during the initial sonar survey.

3.3.2 Oscilloscope analysis

The amplitude of echo signals can be measured much more precisely with an oscilloscope than from an echogram. An oscilloscope can be used to count individual targets more accurately since correct depth-dependent thresholds can be established and the sampling volume can be more precisely determined. In addition, the amplitude of the individual target echoes can be measured. The amplitudes are a function of both the size of the targets and their location with respect to the directivity pattern of the transducer. However, the effects of the directivity pattern can be separated, leaving the distribution of fish target strengths, which provides information on the size of the fish (Forbes and Nakken, 1972; Ehrenberg, 1972). In some cases, large fish can be readily separated from smaller fish and estimated on the basis of their greater target strengths. An example is the adult sockeye salmon (Oncorhynchus nerka) which is acoustically counted in Lake Washington in the United States (Thorne and Dawson, 1974).

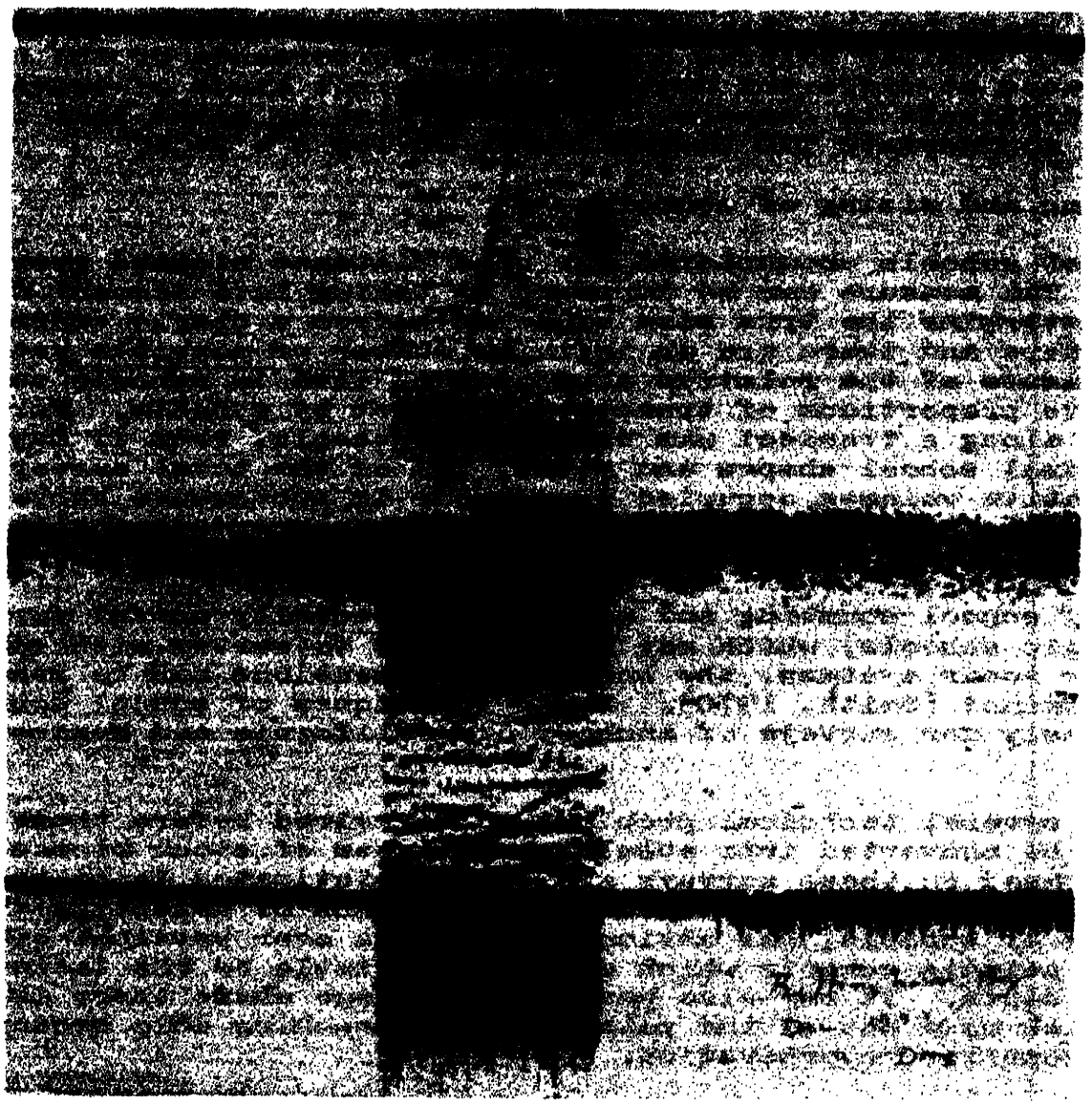

Figure 7. **Effects of variation of gain and "white line" settings on the appearance of the echo trace**

As described earlier, the squared amplitude of the echo is directly proportional to the fish density. The oscilloscope displays the amplitude, and this information can be used to estimate the fish density from multiple targets more accurately than from an echogram. This technique was used by Truskanov and Scherbino (1966) to estimate the abundance of Atlanto-Scandian herring. It works particularly well for fairly uniform distributions, for example, extensive fish layers, but is subject to considerable error where distributions are irregular. This is because it is difficult to estimate the average squared amplitude from an irregular trace, and there is no permanent record for later measurements. The problem is reduced if the data are first recorded on analogue magnetic tape (Thorne et al., 1972).

3.3.3 Automatic signal processing systems

Both echo counting and echo amplitude measuring can be done with automatic systems. Descriptions of echo counting systems which have been used in acoustic surveys are given by Dowd (1967, 1974), Craig and Forbes (1969) and Carpenter (1967). The most commonly used automatic echo amplitude-measuring system is the echo integrator, which measures, squares, and sums the squares of echo amplitudes. Echo integrators provide an estimate of fish density whether the targets are individual or multiple or a combination of both. Information on the average target strength is required to derive absolute density values. The most widely-used echo integrator is the Simrad QM, which is an analogue system. Examples of its use in acoustic surveys are given by Midttun and Nakken (1973) and Johannesson (1975). Improvements in stability (i.e. consistency of performance) and dynamic range (i.e. the range of echo amplitudes measured accurately) can be obtained with digital systems, such as the recent digital echo integrator developed at Aberdeen, Scotland (Simmonds, 1975). The most versatile system is that based on the digital computer (Thorne, 1973). The present digital hydroacoustic data acquisition and processing system used at the University of Washington is based on a PDP 11/45 computer (Digital Equipment Corporation) and can provide estimates of fish density in up to 50 different depth intervals simultaneously, whilst also making target strength measurements or doing routine data processing (Thorne et al., 1977).

3.4 Sampling Considerations

The objective of an acoustic survey is usually to obtain an estimate of the total fish in an area, or of the size of a particular fish stock as a basis for management of a fishery. Since the volume of water searched by an echo sounder is usually a small portion of the total volume, an estimate of the total abundance within an area is obviously affected by variability in fish distribution, as well as uncertainty associated with the acoustic system or technique. Another, perhaps less obvious, uncertainty concerns the assumptions about the biological system being surveyed. Examples of such uncertainty include questions about availability to the acoustic gear (portions of fish too close to bottom or surface), species composition, or seasonal variations in local abundance caused by migration patterns.

Sources of uncertainty can be partitioned into three categories. The first is statistical, due to the inherent non-uniformity of fish distributions within the survey area. This error is reducible through increased survey effort. The other two categories of uncertainty are systematic, or biases. They are not directly reduced by increased acoustic survey effort, nor can they be evaluated by statistical techniques. One category is uncertainty as to the true values of the acoustic parameters, such as target strength; the second is uncertainty as to the availability to the acoustic equipment and biological characteristics of the target stock.

3.4.1 Statistical considerations

Since a population estimate is based on an estimate of the mean fish density from a sample of measurements of fish densities, a measure of the variability of fish density, and thus of the degree of confidence we can place in our estimate of mean density, can be obtained by evaluating the variability among the fish density measurements in our sample. These density measurements are normally expressed as absolute, or relative, values (depending on which of the methods described in section 3.3 has been used) per unit area or

distance surveyed on the acoustic transects. The estimate of mean density and its variance can be calculated from the following equations:

$$\text{mean density } \bar{x} = \frac{\sum_{i=1}^{n} x_i}{n}$$

where x_i are estimates of fish density (e.g. density on each transect) n is the number of estimates of fish density

$$\text{Var}(\bar{x}) = \frac{s^2}{n} = \frac{\sum_{i=1}^{n} x_i^2 - n\bar{x}^2}{n\,(n-1)}$$

The estimate of the total number of fish N in the area is the estimated mean density times the volume (V) in the area i.e. $\hat{N} = V\bar{x}$ and the 95% confidence interval for the population estimate can be calculated from the formula:

$$\text{C.I.} = \hat{N} \pm (t.95.df)\,(V)\sqrt{\text{Var } \bar{x}}$$

where t.95.df is the value of the "t" distribution appropriate to a 95% confidence interval and to n-1 degrees of freedom.

If several areas of different densities are involved, the total number N_t or weight of fish can be obtained by summation:

$$\hat{N}_t = \sum_{j=1}^{m} V_j \bar{x}_j$$

where m is the number of areas and V_j and $\bar{x}_j$ are the volume and mean density respectively in area j.

The variance of the estimated total fish abundance is

$$\text{Var } \hat{N}_t = \sum_{j=1}^{m} V_j^2 \,\text{Var}(\bar{x}_j)$$

and confidence intervals can be similarly calculated:

$$\text{C.I.} = N_t \pm t.95.df \sqrt{\text{Var } N_t}$$

where df

$$\text{where df} = \sum_{j=1}^{m} (n_j - 1)$$

Theoretically acoustic data do not usually have the ideal characteristics which are the basis of the above equations because the data are generally taken serially along some preset trackline and thus are not completely independent, and because fish densities are often distributed lognormally (Figure 8). However the mean density will be normally distributed even if the individual observations are lognormally distributed and serial correlation is not likely to be a serious problem. Further discussion of statistical

considerations in survey design and data analysis are given in Gulland (1975), Bazigos (1975, 1976), MacNeill (1971), Shotton and Dowd (1975), Thorne et al. (1971) and Mathisen et al. (in press).

3.4.2 Systematic errors (biases)

As explained earlier, systematic errors or biases are of two types: those associated with the acoustic parameters and those associated with errors in the assumptions concerning the environment in which we are working. Errors in the acoustic parameters include errors in the system calibration and errors in the measured or assumed target strength. Of these two, the system calibration is the most critical, as the accuracy of both relative and absolute estimates is directly limited by the accuracy and reliability of the acoustic system calibration. On the other hand, relative estimates of abundance, for example, year-to-year evaluation of relative abundance, can be accomplished without precise target strength information.

Another potential source of error in this category is noise from non-biological sources, such as propeller noise or noise from the power supply. Echo integration systems are especially sensitive to this type of problem.

The other category of error includes those associated with uncertainties about species composition, availability of fish to the acoustic gear, and questions of stock identity and migratory behaviour. Acoustic techniques will not provide species identification directly, but often there are clues to identity in the acoustic records which, with experience, can be applied. In some cases, catch records from a fishery can be used for species information. As a general rule, however, direct sampling of the targets giving the return echoes is necessary, especially in the early stages of a study when basic knowledge concerning distribution and echo trace characteristics are lacking. Even with sampling capability, questions may arise because gear selectivity varies between species and with size within a species.

The second problem in this category is the degree of availability of the species to the acoustic equipment. Acoustic systems cannot detect fish on the bottom, and most systems are not well suited for near-surface distributions. A surprising number of supposedly pelagic species exhibit demersal tendencies (Figure 9). Diel acoustic surveys often show greater abundance at night because fish are on the bottom during the day.

The final and sometimes the most difficult problem area is the question of stock identity and migratory behaviour. An acoustic survey is generally aimed at assessing the size of a resource to guide development and management of a fishery. This management is most effective on a unit stock basis. If the identity of the individual stocks and their migration patterns are not known, then problems can occur even with accurate assessments of the abundance of the species in several areas and time periods. For example, it is possible that the same stock could be harvested at two different periods in different areas without this being known, as a wintering stock in one location and as a spawning stock in another. Then even with relatively low apparent exploitation rates in each area, the overall effect on the stock could be substantial. On the other hand, if a stock migrates through an area, a substantial proportion of it may not be present in the area at any one time; alternatively the stock may migrate through the area quickly and be missed by surveys widely spaced in time, or the areal extent of the stock may be greater than assumed. For example, a herring stock which spawns in northern Puget Sound, in the northwestern United States, moves in to the Sound from offshore, spawns and then leaves, all in a short period of time. Consequently, acoustic surveys must be made at frequent intervals to determine the maximum abundance, and even this value may not represent the total population (Figure 10).

3.4.3 General considerations

The above examples illustrate why it is important to consider all sources of error. It is inefficient to expend considerable effort surveying a stock if the acoustic system is uncalibrated and unstable. Conversely, it is not cost-effective to spend considerable funds on

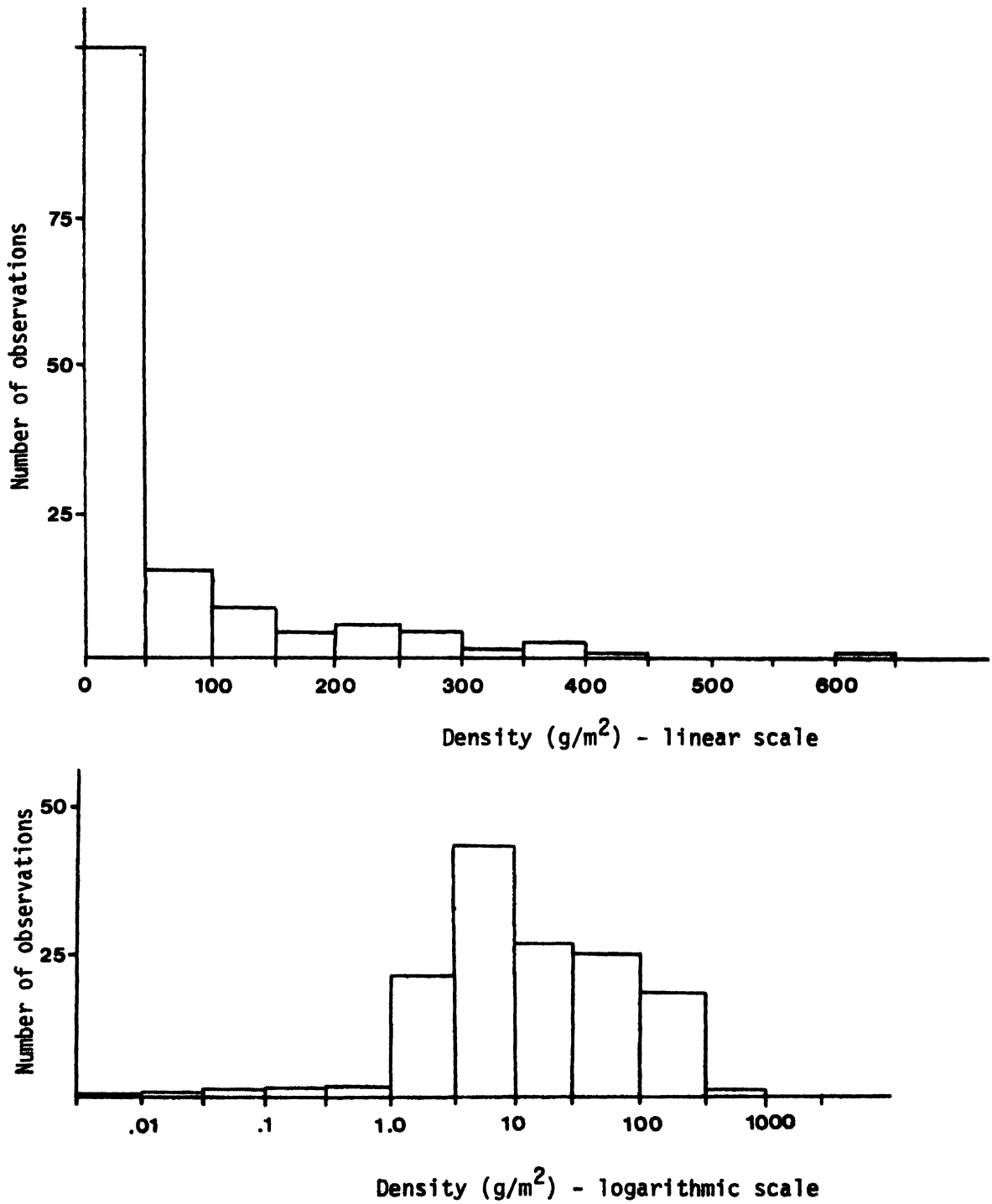

Figure 8. **Frequency distribution of density observations on herring in northern Puget Sound**

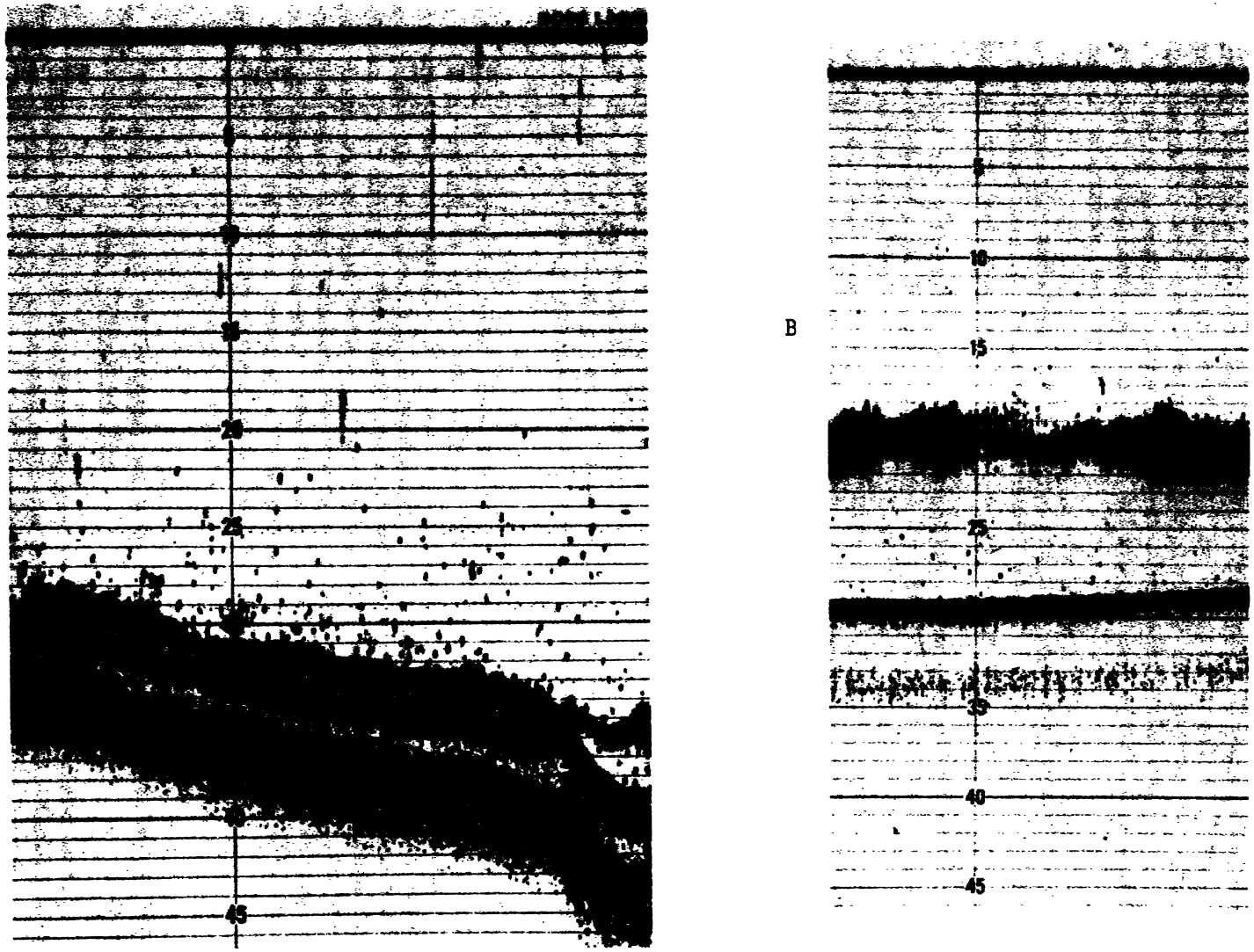

Figure 9. Echograms showing mixed layer of herring and juvenile pollock in Auke Bay, Alaska, January 14, 1975, during afternoon (A) and evening (B), depth scale in fathoms

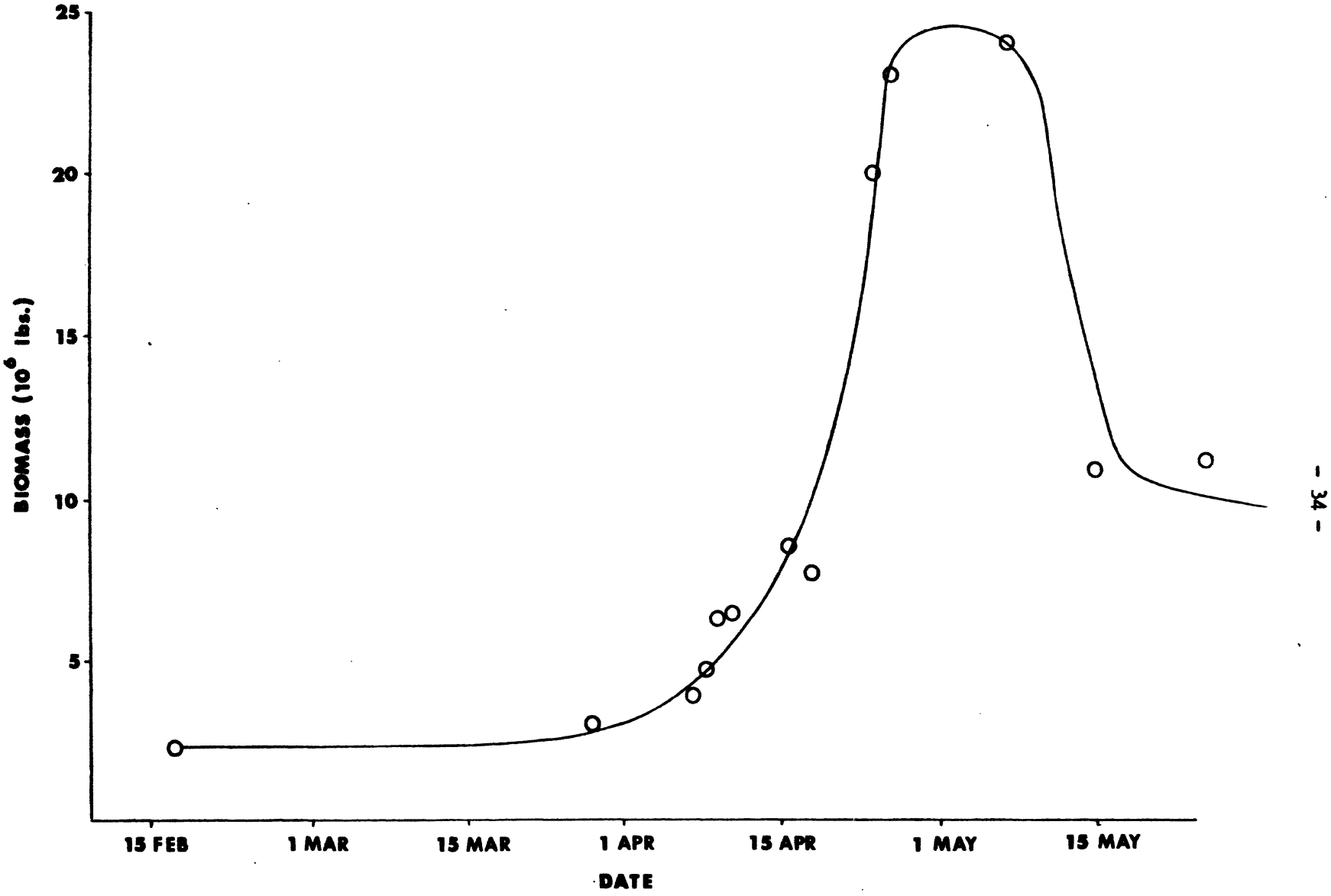

Figure 10. Variation in the biomass of herring in northern Puget Sound during spring spawning period, 1975

a sophisticated acoustic system and apply it to a stock with questionable species composition or unknown distributional characteristics. A biometrician or statistical consultant may be able to help to design a survey and treat the data in order to get a mean population estimate within plus or minus 10%, but the mean may be meaningless. The estimate of target strength may be off by 3dB (a factor of 2) or half of the stock may be located on the bottom unavailable to acoustic gear, or may not yet have entered the area. An electrical engineer or acoustician may be able to develop a highly reliable, accurately-calibrated acoustic data acquisition and processing system, but it will be of little value if the fish are not available to the equipment or are not adequately sampled by the survey design. The fishery biologist who is using acoustic techniques must understand the sources of uncertainty well enough to make sound judgements as to where to expend his effort and money in order to maximize the value of acoustic surveys.

In summary, acoustic assessments can provide fairly rapid absolute or relative estimates of stock size in situations where the stock under study is not distributed so close to the surface, or to the sea bed, as to be unavailable to the equipment.

Where the stock is detectable by echo sounding, the most appropriate acoustic technique of those described above, is largely governed by the equipment and trained personnel available. The most reliable absolute estimate of stock size is provided by echo integration but it must be recognised that this requires sophisticated and expensive electronic equipment which is not widely available, and specialist staff who are capable both of using it and maintaining it in reliable working order. This equipment also demands accurate estimates of the target strengths of the species under study. The measurement of target strength is a complex procedure, outside the scope of this manual, but a good description can be found in Forbes and Nakken (1972).

When such equipment and personnel are not available, much useful information can still be gained by echogram analysis, particularly if the sounder has a good time varied gain facility, using the methods described in sections 3.3.1.1 - 3.3.1.3, and if an oscilloscope is also available by the method given in section 3.3.2. Such methods do, however, require considerably more painstaking analysis subsequent to the survey and a certain element of subjective judgement.

It must also be borne in mind that any form of echo assessment is normally capable of giving absolute or relative estimates only of the abundance of the total assemblage of target organisms in the area surveyed. It does not distinguish between species; and therefore if a species estimate is required it is necessary to sample the organisms which provide the returned echoes by fishing. The catch must then be analyzed for species and for length distributions both within and between species so that the total estimate from the acoustic equipment can be subdivided between the species contributing to it. Purse-seining, midwater trawling or high headline demersal trawling could all be suitable fishing methods for this sampling. The choice between them would be primarily dependent on the depth distribution of the returned echoes and on the vessel and fishing gear available.

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4. INDIRECT METHODS FOR FORECASTING FISHERIES POTENTIALS

There are several approaches to the assessment of the potential fishery resources of the oceans. In this chapter a review of indirect methods which can be employed will be given. Assessments based on primary production make use of the physical and chemical characteristics of the sea area and of the ecological relations of these to phytoplankton and to higher levels in the food chain, culminating in fish. Zooplankton productivity is one step closer to fish and it may also be used to forecast fisheries potentials. Data obtained from stomach content samples of higher trophic forms, e.g., fish, mammals and guano birds can also provide a first estimate of what fish are available. Although fish egg and larval surveys make use of quantitative observations on the resource itself, this method is considered here as an indirect approach and is discussed in this chapter.

4.1 Primary Productivity

A number of authors have tried to estimate potential fish production of a sea area using data for the annual primary production of that area (Graham and Edwards, 1962; Schaefer and Alverson, 1968; Ricker, 1969; Ryther, 1969). In theory this is a logical and simple procedure. If one has accurate estimates of the annual production of primary organic matter in an area, and knows the paths by which this is transformed into higher trophic levels and the ecological efficiency with which these transfers take place, it would be a simple matter to follow the transfer of primary production to fish flesh and calculate the resulting annual production. Three main factors make this procedure one which is likely, in most cases, to give estimates which are only indicative within an order of magnitude:

(a) except possibly in areas with little seasonal or annual variation in primary production the basic estimates of such production are likely to have very wide confidence limits unless a major effort is expended on repeated surveys;

(b) the food chains by which primary production is converted into fish, and other higher trophic forms, are normally very complex and are generally not known in adequate detail;

(c) information on the ecological efficiency with which energy is transformed from one trophic level to the next is also only known within rather broad limits.

In default of any other basis, however, such work can give useful indications of whether an area is likely to contain fish resources in adequate quantities to justify mounting a survey using more direct methods to assess their potential fish production.

4.1.1 Background information on existing estimates of primary productivity

Many estimates of the primary production in the sea have been carried out based on different methods. Some of these estimates are listed in Lorensen (1976). Steemann Nielsen (1975) also gives a summary of the work on primary production in different areas of the oceans. Soviet scientists have made the most up-to-date world coverage consisting of more than 7 000 productivity observations (Koblentz-Mishke, Volkovinsky and Kobanova, 1970). They have estimated the total primary production of the world oceans as 1.5 to 1.8 x 10^{10} tons carbon fixed annually. Generally sea areas may be divided into three types on the basis of their productivity (Table 5).

- open sea areas, which have the lowest primary production per unit area;
- coastal waters which are intermediate in primary production;
- upwelling areas, which have the highest primary production per unit area.

Table 5. Division of the ocean into provinces according to their level of primary organic production. (Adapted from Ryther (1969))

Province	Percentage of ocean	Area (km^2)	Mean productivity (grams of carbon/m^2/yr)	Total productivity (10^9 tons of carbon/yr)
Open ocean	90	326×10^6	50	16.3
Coastal zone[1/]	9.9	36×10^6	100	3.6
Upwelling areas	0.1	3.6×10^5	300	0.1
Total				20.0

1/ Includes offshore areas of high productivity.

4.1.2 Estimation of fish production from primary productivity estimates

In order to estimate the efficiency of transfer of energy from primary production to fish one has to simplify the complex foodwebs in the sea into a simple chain of trophic levels. This may lead to errors which can make the estimates either too high or too low. In addition, there is the element of uncertainty regarding the efficiency of transfer of energy from the primary to the secondary and from the secondary to the tertiary production. Finally, it may be difficult to know at which trophic level one is harvesting. Several fish species will act as herbivores during one part of their life cycle and carnivores during another (Ryther, 1969). Carnivorous fish may also feed at several trophic levels.

Schaefer (1965) has calculated the productivity at the higher trophic levels with three different values of ecological efficiency (Table 6). The choice between two adjacent trophic levels involves a possible error of one order of magnitude or more, depending on the "ecological efficiency" factor chosen.

The figures given in Table 6 are simplified and do not take into account that the ecological efficiency of a fish will change during its lifetime. Young fish may have an efficiency of 15-20 percent, while older individuals may have an efficiency of 10 percent or less (Steele, 1965). The overall efficiency of the ecosystem will clearly be highest when harvesting is done at the lowest trophic level (Petipa, Pavolova and Mironov, 1973).

It is symptomatic of the uncertainty about many of the critical factors in the equations relating fish production to primary production that although both Cushing (1969) and Ryther (1969) estimated total fish production in the Peru Current system at about 20 million tons, they arrived at this figure using very different values for the same parameters. As Paulik (1971) has pointed out, if Cushing had used Ryther's ecological efficiency factor of 0.12 rather than the value of 0.01 which he did use, he would have estimated fish production at about 240 million tons. Thus, even in an area which is fairly well-known and which has been the subject of a considerable amount of ecological research one can arrive at very different estimates of fish production by selection of different values within the possible ranges of the parameters.

Table 6. Estimates of annual potential yields at various trophic levels, in metric tons. (Adapted from Schaefer (1965))

Trophic level	Ecological efficiency factor					
	10 percent		15 percent		20 percent	
	Carbon	Total weight	Carbon	Total weight	Carbon	Total weight
0. Phytoplankton (net particulate production)	1.9×10^{10}		1.9×10^{10}		1.9×10^{10}	
1. Herbivores	1.9×10^{9}	1.9×10^{10}	2.8×10^{9}	2.8×10^{10}	3.8×10^{9}	3.8×10^{10}
2. 1st stage carnivores	1.9×10^{8}	1.9×10^{9}	4.2×10^{8}	4.2×10^{9}	7.6×10^{8}	7.6×10^{9}
3. 2nd stage carnivores	1.9×10^{7}	1.9×10^{8}	6.4×10^{7}	6.4×10^{8}	15.2×10^{7}	15.2×10^{8}
4. 3rd stage carnivores	1.9×10^{6}	1.9×10^{7}	9.6×10^{6}	9.6×10^{7}	30.4×10^{6}	30.4×10^{7}

4.1.3 Methods of measuring primary production

Various methods can be used to measure the primary productivity. One may for example estimate the in situ production from samples of water collected from specific locations and depths by measuring oxygen production or uptake of carbon.

Until about 1950 the most common method was to measure the oxygen production. The amount of oxygen released in a given volume of water during a time period is proportional to the amount of carbon assimilated through photosynthesis. When the amount of oxygen produced is measured one can therefore calculate the phytoplankton production (Steemann Nielsen, 1975). This method is time-consuming, rather laborious and difficult to carry out in situ. Moreover, if the primary production is low, the sensitivity of the method used (Winkler method) for measuring dissolved oxygen is inadequate. Nowadays therefore oxygen measurement is almost completely substituted by direct measurement of carbon assimilation. This method was developed in the early 1950's and makes use of radioactive carbon (^{14}C). The method is quite simple but requires some knowledge of working with tracers (Vollenweider, 1974). To a certain volume of water is added a known amount of ^{14}C and after some time the phytoplankton is removed by filtration. The filter is fumed in HCl and the ^{14}C assimilated in the phytoplankton is measured. When this method was first introduced the assimilated ^{14}C was measured by a Geiger-Müller counter. This has now been commonly replaced by liquid scintillation counting which together with other modifications, has made the method more accurate (Schindler, Schmidt and Reid, 1972; Cushing, 1975). Steeman Nielsen (1975) states that the accuracy of the ^{14}C technique is not more than about ± 30 percent. Considering the enormous variation of the rate of primary production in nature this is acceptable.

Primary production can also be estimated by measuring directly the quantity of phytoplankton per unit volume of water. From this standing stock the productivity can be estimated if the turnover time is known.

The amount of certain plant pigments in the water has also been used as an index of standing stock. The pigments, especially chlorophyll *a*, are extracted from the plankton by using 90% acetone, and the amount is measured by spectrophotometry or fluorometry (Strickland and Parsons, 1968; Cushing, 1975). This method, however, has the disadvantage that it does not show if all the pigment measured is active in photosynthesis because it also includes the degradation products of chlorophyll (phaeo-pigments). Recently, measurements of fluorescence before and after acidification of the sample have permitted estimation of the amount of phaeo-pigments, thus allowing a better estimate of active chlorophyll *a* (Strickland and Parsons, 1968). These methods are thought to be less accurate than the oxygen or ^{14}C methods.

Another method under development is based on excitation fluorometry of chlorophyll *a* (Samuelsson, Oquist and Halldal, 1976). The pigment will release an amount of fluorescent light which is inversely proportional to the photosynthetic activity, depending on physiological conditions. When the photosynthetic activity is at a minimum, the amount of fluorescent light reaches its peak. By measuring the emitted fluorescent light of chlorophyll *a* *in vivo* before and after stopping photosynthesis by adding poisonous chemicals, one gets a measure of the amount of chlorophyll *a* and an estimate of relative productivity. The advantage of this method is that it can be run continuously during a cruise, and it is possible to get consecutive measurements of the primary production at a certain depth. The method can also be applied to water samples from deeper layers. Although not fully developed at present, this method seems promising and may simplify the measurement of primary production.

4.1.4 Evaluation of usefulness of primary production estimates as a guide to fish production

Even in the situation where the annual primary production can be measured, with acceptable accuracy, easily and cheaply it is clear from what has been said above that estimating from this the production of fish is likely to provide only very rough answers unless a great deal of basic background information is available on the total biota of the area under study, of the inter-relations between the elements of this biota at all stages of their life-cycles, and on the efficiency of energy transfer between them. In most sea areas therefore, where little such information is available, it cannot be advocated that the necessary effort should be expended on producing precise estimates of primary production.

However where even rough estimates of this production are available some useful first estimate of likely fish production might be obtained by comparison with other areas, for which both estimates of primary production and of fish production are available in the literature. Provided the species of fish available in the two areas are feeding at the same trophic level it would be a reasonable assumption that the fish production in the two areas would be roughly proportional to their primary productions. An estimate of fish production obtained in this way would be unlikely to be sufficiently reliable as a basis for developing a fishery; but it could provide a first estimate on which to base a judgement whether a project to assess the potential by more direct methods was justified.

4.2 Zooplankton Abundance

As with phytoplankton, the abundance of fish and other higher marine forms must be related to the standing stock of zooplankton, and attempts have been made to forecast fishery potentials from the standing stock of zooplankton (Cushing, 1969; Ryther, 1969). However, the problems of measuring standing stocks and estimating total zooplankton production are generally greater than for primary production. The total standing stock biomass of zooplankton can be assessed, but the sampling coverage required in time and space is considerable and involves a good deal of costly survey vessel time.

Plankton gears are generally very selective and several types of sampling devices are required to collect different components of the zooplankton (Fraser, 1968; Ackerfors, 1971). The need for more comprehensive quantitative knowledge of zooplankton has highlighted many sampling problems. Questions arose concerning mesh size and material, the volume of water filtered, measurement of the depth of sampling, closing devices, speed of tow, avoidance, etc.

By modifying the mesh size of the net it is possible to catch certain portions of the available zooplankton. If one uses the finest mesh sizes to enable the capture of the smallest zooplankton organisms, the net is not effective for capturing larger zooplankton. Therefore, a variety of nets and mesh sizes need to be used, to sample the different size fractions of the total zooplankton population.

In order to get reasonable abundance estimates, one has to know at which depth the net is sampling. Until recently the sampling depth has mainly been estimated from the length of wire used and the wire angle. Today, the sampling depth can be measured accurately, e.g., by depth-time recorders. More sophisticated telemetering systems have also been developed to estimate the gear depth. The information can be passed back to the ship either electrically through a cored cable, or by sound impulses transmitted through the water and picked up by a towed microphone. The depth can then be adjusted if desired during towing.

In summary, the variety of forms and size groups make it difficult to obtain quantitative estimates of the total standing stock of zooplankton. Differences in generation time make it even more difficult to calculate zooplankton production, i.e., the amount of new material being produced per unit of time. Although standing stocks of many important zooplankton forms are commonly estimated, this work seems to be of little value in forecasting fishery potentials. The results obtained, however, may be quite useful in future, particularly if new technology makes it possible to harvest the larger zooplankton forms directly. As pointed out in section 4.1.4 the likely accuracy of any direct estimate of fish production, derived from estimates of zooplankton production, would not seem to justify initiating a survey programme with this objective. However, if reasonably sound estimates of zooplankton production are available they should be utilized to make a rough comparison with any other area for which both zooplankton production and fish production estimates are available. Again, however, it is necessary to take account of the trophic level at which the fish stocks in the two areas to be compared are feeding.

4.3 Egg and Larval Surveys

Surveys to estimate the abundance of the planktonic egg and larval stages of fish could, theoretically, be used both for: (a) estimating future recruitment to the stock and (b) for back calculating the size of the stock which would have been necessary to produce that number of early stages. In practice, in fish stocks which have not been over-exploited there is generally no direct relationship between the abundance of the early stages, and the recruitment; the first of these procedures therefore is not normally practicable, although surveys to estimate recruitment from some later, post-planktonic stage may be desirable.

The concept of estimating the abundance of the spawning stock of a fish population from egg and larval surveys is simple. The spawning stock size can be obtained from the following expression:

Total number of eggs produced during one spawning season = number of spawners x proportion of females in the spawning stock x average numbers of eggs produced per female.

i.e. $N \overset{P}{}$

where N = number of mature fish in the stock
P = annual egg production of the stock
F = mean number of eggs produced annually per female
R = proportion of females in the mature stock

Thus, if the number of eggs produced during a year can be estimated, and the proportion of females in the stocks and the average number of eggs produced per female per year are known, the size of the spawning stock can be calculated.

The techniques for sampling eggs will be different for species with planktonic eggs and species with demersal eggs. For species in which the egg stage is planktonic there is the obvious advantage that they are usually concentrated in the upper layer of the sea, where sampling with relatively simple plankton gears, for which the swept volume can be easily measured, is possible. Demersal eggs can be sampled by divers or by use of grabs (Gjosaeter and Saetre, 1974).

The equation above will give the size of the spawning stock in numbers. Generally however one is more interested in the weight of the stock. In practice the relationship between fecundity and weight is usually a simpler one than the relationship between fecundity and length. So it is preferable to use fecundity per unit weight in the above expression rather than average number of eggs per female. In that case it will give the weight of the spawning stock directly.

An estimate of number of eggs produced may be obtained by sampling eggs of known age at a series of points in time and location and then integrating over area and time to get the total production. Estimates of egg production may also be based on abundance of larvae of a certain age but in that case the observed number should be corrected for any mortality occurring from the time of spawning up to the larval stage in question. The time that the spawning products remain in the stage used in the estimate must also be known in order to be able to calculate how many days' production the observed numbers represent.

The procedure to get from survey values of the standing stocks of eggs to an estimate of the size of the spawning stock can probably be best illustrated by a worked example:

Period of survey	Estimated egg abundance in surveyed area	Daily egg production
3-5 September	8225×10^6	3290×10^6
6-8 September	122765×10^6	49106×10^6
10-12 September	413795×10^6	165518×10^6
13-15 September	530215×10^6	212086×10^6
16-17 September	609375×10^6	243750×10^6
19-21 September	438020×10^6	175208×10^6
23-25 September	209225×10^6	83690×10^6
26-28 September	55288×10^6	22115×10^6
29 September-1 October	2313×10^6	925×10^6

The eggs take 2.5 days to pass through the stage used in the estimates of standing stock. By dividing the values in column 2 in the table above by 2.5 one therefore gets the values of daily egg production given in column 3. To integrate these values over time they are then plotted against the mid-date of each survey as in Figure 11. The area under this graph is equal to 153.25 large squares each of which represents 2×10^{10} eggs on the scale used. The total annual egg production is then equal to $153.25 \times 2 \times 10^{10}$ eggs = 306.5×10^{10}. The fecundity-weight relationship of this stock is $F = 22.4W$, where F = fecundity of a female of weight W in grams. Thus each 22.4 eggs produced represent one gram of female spawning biomass, which in total must have amounted to $(306.5 \times 10^{10}$ eggs)/(22.4 eggs/gr) = 13.7×10^{10} gr = 137×10^3 tons. If the sex ratio of the spawning population (by weight) was 1:1 during the survey, the total spawning biomass (males and females) was $2 \times 137 \times 10^3 = 274\,000$ tons.

There are, however, a number of prerequisites for the successful use of this method to obtain accurate estimates. The problems of identifying the eggs and larvae must be solved, and the extent of the possible spawning areas and the period of time over which spawning may take place should be known to give a basis on which to plan an adequate sampling programme (Saville, 1964; Saetersdal, 1973). In the warm waters of the tropics and subtropics the development of the eggs and larvae is rapid and this can cause special sampling problems with regard to coverage. At low latitudes the spawning of fish is often less restricted both in time and in location than in colder regions and this also increases the research effort needed.

The errors involved in estimating the annual production of fish eggs and larvae have been discussed by several authors, e.g., Saville (1964), English (1964).

The main sources of variance are:

- the variation between hauls made at the same location;
- the variation in abundance between locations;
- the variation in time within a spawning season.

The first two sources of variation will give a variance on the estimated egg or larval abundance at the time of a single cruise. The main contribution to this variance is usually the variability between locations and to minimise this source a stratified sampling design, similar to that described in Chapter 2 for resource appraisal surveys should be adopted.

The main contribution to the variance of the estimated seasonal egg production will, however, in most cases be the variability in time. It is obvious that large errors can be introduced if sampling is confined to relatively short periods. One may happen to sample the eggs or larvae at the peak of production in one year but miss it in another year. Thus, both absolute and relative estimates of abundance may be subject to large errors. To plan the best sampling design the range of spawning time and the timing of its mode(s) should be known.

In the example shown in Figure 11 the spawning season is relatively short and within this the frequency of egg production follows fairly closely a normal distribution. This is an ideal situation in which estimates of the annual egg production of adequate accuracy could be obtained by a lower survey frequency than was used in that instance. In the case of a longer period of spawning, and a less regular sequence of egg production, the survey frequency necessary to get a sufficiently accurate estimate of annual egg production may be too great to make this method of assessing spawning stock size practicable. As in the case of estimating egg production within a survey from individual station observations, a major gain in precision can be achieved by increasing sampling near the expected modes of the production curve, and decreasing the frequency at its tails.

There are also some possible sources of bias in the estimates. Of these eggs and/or larval mortality is the main one. An estimated number of eggs or larvae of a certain age should be corrected for any mortality which has occurred up to the end of that age. There are very few instances where egg and larval mortality has been adequately measured and to do so demands a major input of effort aimed specifically at this objective. Wherever practicable therefore assessment of stock size should be based on the earliest stage after spawning possible - preferably on a stage where maximum age is not greater than three days. The few adequate measures of mortality available would suggest that mortality during these early stages is of the order of 5-10 percent per day. A reasonable approximation would therefore be to divide an estimate of early egg production by 0.9 to correct for mortality during this stage.

Errors may also arise from the estimation of fecundity. These are likely to be of minor importance for total spawners but estimating fecundity is rather difficult for

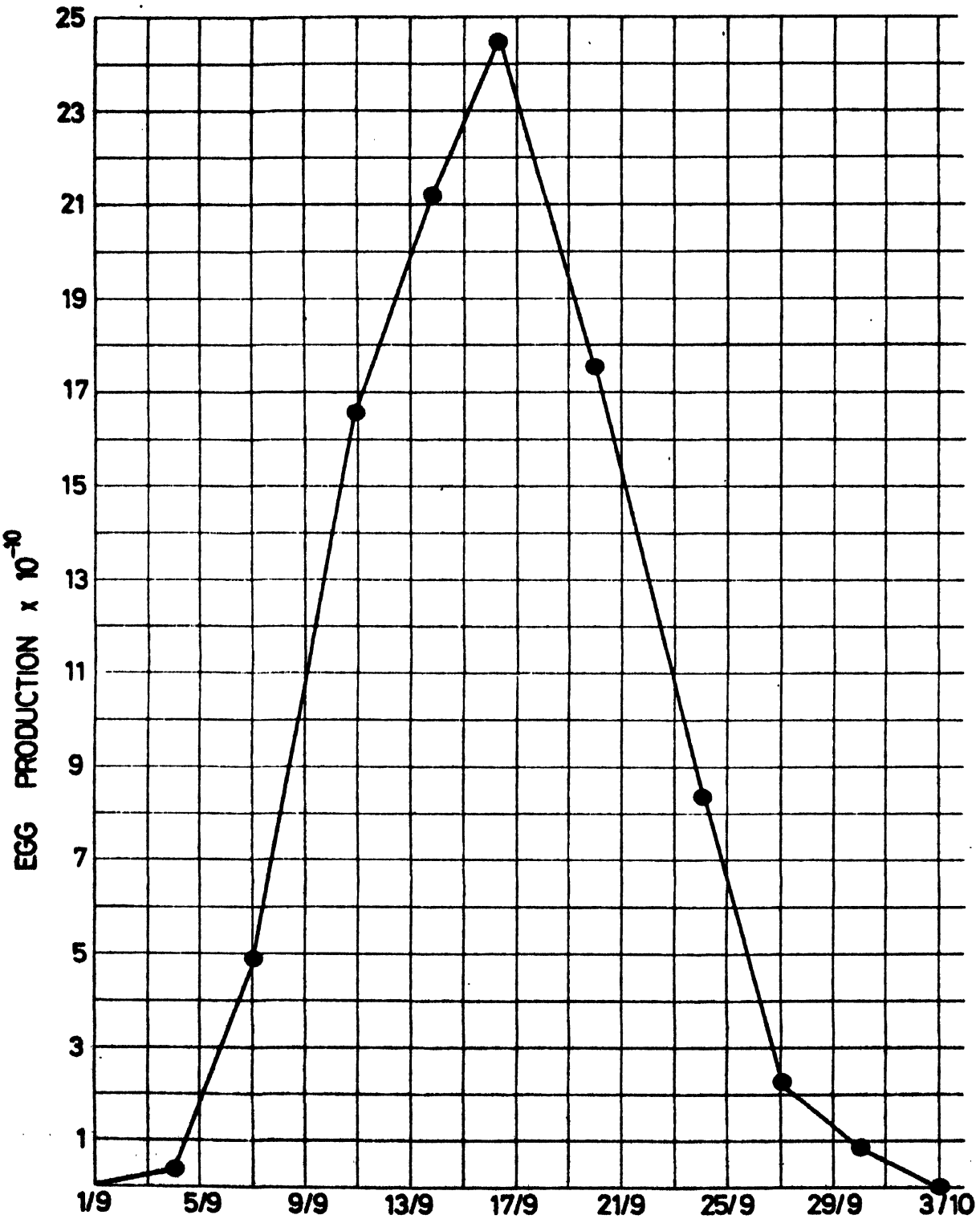

Figure 11. Plot of estimated daily egg production against mid-date of survey

serial spawners because in their early maturity stages all the oocytes due to be spawned in one spawning cycle may not yet have been differentiated and, in later stages, some of the first eggs to develop may already have been spawned. To get an estimate of annual fecundity for such species it is necessary to know the number of spawnings per year, the number of eggs shed in each batch and the relations between these factors and the size and age of the fish. Fischer and Balboutin (1970) have described techniques for sorting oocytes into size groups and subsampling them whilst Macer (1974) has described a method based on histological examination of ovaries during a complete spawning cycle. This method has given useful results for horse mackerel but is very time consuming.

Thus the methodological problems in and the confidence limits of assessments based on egg or larval surveys will depend very much on the extension of the spawning in time and location. In cases where the timing of intensive spawning is not known, or is wide, repeated sampling over the whole spawning period is necessary to avoid large errors. Such repeated sampling will require a great deal of sampling effort if spawning takes place over a large area.

Despite the potentially large errors which could be involved, there are a number of examples which show that such surveys can be useful (Saville, 1965; Tanaka, 1974). They may also be helpful in detecting the presence of potentially exploitable fishery resources in little known areas. A detailed discussion of the planning and conduct of ichthyoplankton surveys is given by Smith and Richardson (in press).

Generally speaking, egg and larval surveys make heavy demands on vessel time and also on specialist staff for processing the samples. The sampling operation is, on the other hand, simple and can be done with almost any type of vessel. The costs of such surveys will still be rather high and a careful comparison should always be made of the relative cost effectiveness of this and the other more direct survey methods discussed in the preceding chapters. Sampling for eggs and larvae can often be incorporated into other survey programmes without much additional cost and effort. The sampling design of such surveys will, however, seldom meet the requirements of proper egg and larval survey and the material collected will therefore be of only limited value for resource assessment. Useful indications may still emerge from such incidental programmes on the distribution of spawning concentrations of fish and on what fish are available in the area. Although it cannot, in most circumstances, be advocated that egg surveys be undertaken specifically to estimate stock size, data already available on egg abundance should certainly be examined to see whether even rough estimates can be derived from them to set the scale of other work.

4.4 Examination of Stomach Contents of Higher Trophic Forms

The stomach contents of carnivorous fish or other animals feeding near the top of the food chain may provide useful indications of the presence and rough estimates of the abundance of fish resources. The abundance of the predators themselves will in such cases be an important parameter in assessing the data.

Theoretically if one knows the abundance of the predators feeding on the resource which one wishes to assess, the annual energy requirements of an individual predator, and the proportion of the food intake of the predator which the species under investigation provides, one can calculate how much of that resource the predator is removing from the sea annually. This then provides a lower estimate of the production of the resource. To refine the estimate beyond that level requires an estimate of the natural mortality rate of the resource which is being assessed, and of the proportions of that mortality caused by disease, other predators, etc. The calculation of accurate estimates of production from this sort of data therefore demands a very complete knowledge of the ecology of both the prey species and of the predator; and this is very rarely available. This approach therefore is only likely to be appropriate to give a first, minimum estimate of the size of a prey stock that is the dominant food of a large predatory population, which can in

its turn be more readily assessed, or has already been assessed. Examples where this type of approach have been utilised are Peruvian anchoveta from the abundance of guano birds and the guano production (Schaefer, 1970) and Antarctic krill from whale abundance (Everson, 1977). Changes in the stomach contents of a predator may also indicate changes in the abundance of a prey species. Analysing stomach contents of higher organisms may be a rather cheap way to get useful information as it may be a spin-off from other biological investigations.

An estimate of absolute abundance with any degree of precision can, however, very rarely, if ever, be expected from this method. This is due to uncertainties concerning, for instance, the selectivity of a predator. The predator may prefer certain fish species and certain size groups of the prey, or it may not discriminate among food items, taking anything available. Feeding habits may also vary in time and space.

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5. DATA COLLECTION AND RECORDING

The methods employed in collecting data and the ways in which these data are recorded are of vital importance to the successful conclusion of a fisheries survey. Data collected at sea are unique and costly and if the initial information is recorded incorrectly or inadequately the later stages of the analysis may be invalidated and the objectives of the survey may not be achieved.

In many cases information is recorded under adverse conditions and personnel may not be operating as efficiently as they would on shore. It is important, therefore, that all sea-going staff are trained in the essential features of data recording and that a systematic method of handling data is used by all the staff engaged on a survey. Associated with this is the design of appropriate recording documents which will ensure that the information to be collected is systematically recorded and can be easily checked, and that further analyses do not involve unnecessary transcribing of data.

When large volumes of data are to be collected it is quite common for the information to be processed automatically. This involves other staff than those who recorded the information at sea. Frequently these data processing staff will be unfamiliar with the material recorded and will enter information into the computer exactly as written. Incorrectly recorded data, illegible, or ill-formed numbers therefore may present problems which will not necessarily be corrected at later stages and which could thus lead to incorrect conclusions being drawn from the analysis.

5.1 Data Selection

It is difficult before an exploratory survey begins to know precisely the type and quantity of information to collect. It is natural to try to record as much as possible and in as great detail as possible. One then finds that this puts too heavy a strain on sea-going staff, to the detriment of the really essential data. Frequently much of the subsidiary data recorded in this way cannot be used, as it is not quantitative or is recorded in a non-standard way.

The officer in charge of a survey has the responsibility for the success of the project and must decide on the essential data to be recorded and distinguish these from the merely desirable. He must ensure that the standards of data recording laid down for the survey are maintained and that the requirements demanded of the cruises are compatible with the numbers and level of staff available to carry out the duties.

The main objectives of a fishery survey are normally to estimate the distribution, abundance and potential yield of certain species within the survey area. For this purpose it is necessary to record precise information on where each species was caught, the conditions under which the catches were taken, when the catch was taken and the amount taken for a given unit of effort. The amount caught may be recorded in various ways (e.g. number of baskets, total weight, numbers of fish) depending on the objectives of the survey, and the conditions on board.

It is essential that these major objectives are borne in mind and that the documents prepared before the cruise are suitable for recording the required information. The staff concerned with recording the information must be instructed in the correct procedures and the standard of documentation expected.

5.2 Data Records

Properly designed recording documents will make the correct recording of essential data easier and less time-consuming. If the information collected on a fisheries survey is to be collated and analyzed by a computer it is necessary to have data recorded in a precise format, and any ambiguities must be resolved before the recording documents are presented to the computer centre. For this reason, staff concerned with the computer processing of cruise

results must be consulted on the design of recording documents, and their essential requirements should be included in the design.

If data have to be prepared on punched cards prior to computer analysis, the recording document should reflect the punch card format, so that the cards can be easily and quickly punched. There are forms of computer input other than punch cards which may be used by a computing centre and the needs of these methods of input should also be considered where appropriate.

The major features of a good data record are:

(a) It is convenient for recording information, i.e. it contains sufficient space for entering numbers without cramping them and the layout of the document follows the natural operations of the recording staff. It is extremely annoying to have to record at the top of a sheet, go to the bottom of the sheet for the next entry, and then return to the top again for the third entry.

(b) It is explicit in its requirements. The document should have titles and questions preprinted so that recording staff know precisely the nature and quantity of information to be recorded.

(c) It can be used for subsequent processing without the need for transcription to another document. Copying information by hand from one document to another is very inefficient, and is often a source of major errors.

(d) Its layout is as clear and simple as possible, to enable a supervisor to check for major errors or misrecordings.

(e) It should be preprinted with as much information as possible to reduce the amount of writing done at sea. If two or more copies of the data are required these should be made at the same time with self-copying paper.

Several documents are usually required to record all the information collected during a survey. These are in the following categories:

(i) a log which summarizes the whole cruise;
(ii) details of individual stations or hauls which will generally provide information on the vessel's position, data and time of the station and information on the type of work done, e.g. giving details of the kind of fishing gear used;
(iii) information concerning catch, which will often be in the form of length frequency distributions;
(iv) a document to record special biological information;
(v) an echo sounder survey log.

Included here are some examples of documents designed for fisheries surveys which have proved to be effective, not only as convenient documents for recording data at sea but also for subsequent analyses, whether done manually or by computer. These forms were, of course, designed for a particular laboratory's requirements and so will require modification to suit the needs of other surveys. For example, they are not directly suitable for transferring the information to punch cards, but could easily be adapted if this were a requirement.

5.3 Survey Identification and Description

Many fisheries institutes make a wide variety of cruises each year with different objectives, e.g. exploratory fishing or resource surveys, acoustic surveys, or others designed essentially to collect environmental information. Each cruise must be identified and classified as to its nature so that the information collected can be retrieved correctly and economically at a later date.

If an exploratory survey is to be done by several vessels, possibly as a collaboration between different laboratories or countries, an agreed method of identifying the survey must be used and standardized methods of reporting the collected information should be considered

HAUL SUMMARY SHEET

Haul No.

Gear

Date

Stat. Square

Time Shot	Time Hauled	Duration	Course	Revs	Warp Aft	Depth (Fathoms / Metres)

Latitude Shot	Longitude Shot	Latitude Hauled	Longitude Hauled	Sky	Wind Dir. & Force	Station No.

Decca Readings Shooting	Decca Readings Hauling	Region
R G P	R G P	

Total No. of Baskets		Catch Composition Large Mesh	Catch Composition Small Mesh
Large Mesh	Small Mesh		

Remarks (Damage to Gear etc.)

Numbers Caught (Raised)				Numbers Caught (Raised)				Numbers Caught (Raised)			
Code	Species	Large Mesh	Small Mesh	Code	Species	Large Mesh	Small Mesh	Code	Species	Large Mesh	Small Mesh
8	Scyllium canicula			9255	Weever						
9	Pristiurus			9263	Mackerel						
24	Squalus acanthias			9275	Gobies						
32	Spinax niger			9290	Dragonets						
941	Skate			9293	Blennies						
64	Chimaera monstrosa			299	Lumpenus lumpretaeformis						
73	Sprat			9305	Catfish						
74	Herring			320	Sarpacena (blue mouth)						
88	Argentina silus			324	Sebastes viviparus				INVERTEBRATES		
89	Argentina sphyraena			325	Sebastes marinus				Lobster		
131	Conger eel			9326	Gurnards				Spiny Lobster		
9154	Macrouridae (rat-tails)			345	Lumpsucker				Nephrops		
160	M. bouteasseu			353	Turbot				Pandalus		
161	Whiting			354	Brill				Crangon		
162	T. luscus			9355	Tephrota				Cancer pagurus		
163	T. esmarkii			358	Megrim				Geryon affinis		
164	T. minutus			9360	Scaldfish				Geryon tridens		
165	Gadiculus			363	Common Dab				Spider crabs		
166	Lytha			364	Flounder				Loligo		
167	Saithe			365	Plaice				Alloteuthis		
169	Cod			366	Lemon Sole				Other squid		
170	Haddock			367	Witch				Pecten maximus		
171	Torsk			368	Long Rough Dab				Chlamys opercularis		
172	Greater Fork Beard			369	Halibut						
173	Hake			9371	Soles						
175	Ling			391	Angler						
177	Blue Ling										
9181	Rocklings			OTHER SPECIES							
199	John Dory										
216	Horse Mackerel										
9291	Wrasses										
9280	Sandeels										

Summarised by:

Figure 12. Example of a form used for recording data on a single fishing operation during a survey.

in the survey planning stage. Non-standardized reporting can cause considerable difficulties at later stages when the data are being analyzed. For example, lack of decision on whether to report time as local or GMT will lead to confusion when collating data if analyses involving time of day are required.

It is customary to identify a survey and individual cruises and stations within a survey, by a short name or, in the case of a single vessel cruise, by a short code such as F76/3/10, which would identify the vessel by the first letter of its name, the year of the survey, the survey sequence number signifying in this instance that this was the third survey or cruise in 1976 and the haul or station identification within that survey. Other more elaborate coding methods may be employed to identify a survey and its component parts, but the main point to note is that a systematic procedure is employed and that all personnel involved in recording information are aware of the coding requirements.

Apart from the cruise details other relevant information such as different gear types used during a cruise must be recorded. When frequent changes are made in the course of a survey it is much easier to identify the changes by coded information than to have to write out in full the details of each gear specification each time.

5.4 Station Identification and Recording Observations

Precise and full information must be recorded on where a survey vessel was working, when the work was done and the conditions obtaining at that time. This information is associated with the detailed measurements of species caught and other biological data and forms the basis for the analysis of the data for the whole survey area. The data from individual hauls are frequently aggregated over specified areas or strata, or over separate time periods and it is very important that the information collected defining the location and timing of a station or haul is accurate.

Figure 12 gives details of the kind of information recorded to identify a station or survey position. While this form is designed primarily for trawling or seining operations it can easily be adapted to handle other forms of fishing operation. For example, in purse-seining it may be considered necessary to include searching time as an additional measure of effort, or in longlining the number of hooks may be a required measure. When a particular kind of fishing gear is used an appropriate measure of effort must be defined and incorporated in the recording document. The essential point is that an accurate measure of location, effort and time is recorded during the station.

Figure 12 then provides a complete general summary of fishing operation at the defined station. All information required is requested by the document and can be systematically recorded and verified, by the officer in charge of the cruise, for errors before it is assembled with the rest of the recorded data from the station.

The first part of this form should be completed by the ship's officer responsible for the navigation of the vessel and it is checked by the scientist in charge. The haul number, which is normally allocated in a time sequence, is conveniently displayed so that it can be checked that there is a form for each haul made. Full instructions are given for completing the entries in each location and such instructions should be included in the Standing Instructions for recording data at sea. For example, the instructions for completing this part are:

HAUL NUMBER	A sequence identifying vessel, year, cruise and haul, e.g. B77/2/57. All hauls, whether discarded or accepted at a later stage, must be given a number.
STATISTICAL SQUARE	A code number for an appropriate sub-division of the total survey area. In this case the sub-divisions used are 30 miles square but if this is inappropriate alternative sub-divisions may be used.
TIME SHOT	For a trawl this is defined as the time when the winch is set. For other gears insert the appropriate time for the defined start of the fishing operation. Times should be given in GMT.
TIME HAULED	For a trawl this is the time when retrieval of the net begins. For other gears enter the time for the defined completion of the fishing operation.
DURATION OF HAUL	The difference in time between time hauled and time shot. This entry is often useful for checking possible errors in the previous two observations and may also be the required unit of effort for that haul.
COURSE	Measured in degrees.
REVS	The engine revolutions at which the vessel fished.
WARP AFT	The length of warp paid out during the haul, measured in fathoms or metres.
DEPTH	The bottom sounding from the echo sounder, in metres. Where this varies during a haul give the depth at the beginning and the end of the haul or the range of readings.
LATITUDE SHOT LONGITUDE SHOT LATITUDE HAULED LONGITUDE HAULED	The accurate location at which shooting and hauling were started and completed. The difference between these two positions will allow the actual distance over which the gear was towed to be measured.

SKY	For this entry there are four choices viz. DAWN, DAY, DUSK or DARK. This divides each 24 hour period into four parts and the main features of, for example, DAY hauls can be extracted by classifying by this entry.
WIND DIRECTION (a)	(a) measured in degrees, and (b) on the Beaufort scale. This information may be used to qualify the results of a particular haul.
STATION NUMBER	This is not to be confused with the haul number which is in strict numerical sequence. The station number should be fixed for each fishing position at the survey planning stage and may be the same for cruises of the same kind throughout a survey. It is possible that the stations will be numbered in a way which will coincide with haul numbers but, perhaps because of adverse weather conditions, the hauls will not be done in the quence.
DECCA READINGS	While many areas are not covered by DECCA chains the appropriate readings from any such navigational aid should be inserted, prior to conversion to latitude and longitude. For example, when a position is fixed by range and bearing from an identifiable point on land a space could be left where this information could be directly recorded, and the latitude and longitude checked from this entry.
REGION	This is used to classify the latitude and longitude into a major region which may be a combination of several smaller units such as statistical rectangles. If a survey area was divided into several strata for sampling purposes these strata could be coded prior to the survey, and hauls within each stratum could be recorded under this time as stratum A, B, C etc. or whatever code name is devised.

5.5 Catch Information

The reasons for conducting a fisheries survey are to obtain information on the distribution of the appropriate species and estimates of their abundances. In many cases several species will be caught during a haul, some in large quantities and others in small numbers. Where trawling or seining is the method of capture, frequently either a small meshed codend is used or alternatively a commercial-sized codend enclosed by a small mesh cover. It is useful if a cover is used to collect data on the catches of the normal codend and the cover separately.

In fishing operations there will be many occasions when large numbers of fish are caught and staff on board ship are unable to record information on all fish caught. Several publications (Gulland 1966, Paloheimo and Dickie 1963, Pope 1956) discuss the problems of sampling catches at sea. The essential element of a good sampling scheme is that it will yield an unbiased estimate of the size and composition of the catch. After deciding the sub-sampling procedures to be followed (see Chapter 2) it is necessary to design a document for recording catch information which will ensure that the essential details of any sub-sampling done are easily recorded and that the final estimates obtained can be readily verified.

The minimum requirement is to record an estimate of the numbers or weight of each species caught. Figure 12 illustrates how information on weight and/or numbers can be recorded in a systematic way. This form contains a preprinted list of all the major species likely to be caught on a cruise in the North Sea. The total numbers caught of each species are then recorded in a defined way. Each species also has a code number which, in this instance, is used in subsequent data processing.

However, without needing to await the output from detailed processing, it is comparatively easy for the scientist in charge, at the end of the cruise, to prepare a preliminary report on each major species by summarizing the information contained in these haul summary sheets without referring to the more detailed catch composition or biological data sheets. In exploratory cruises it may be difficult to make up a comprehensive list of all the species likely to be caught, but at the planning stage of a survey an attempt should be made to identify the most likely species or families and a scheme drawn up so that the catch information can be recorded systematically. When a list of species, or species groupings, has been decided on, this should not be modified in subsequent cruises as doing so is likely to make it difficult or impossible to compare results of cruises done prior to the changes with those done subsequently.

5.6 Recording Length Compositions

Length composition data are usually collected on fisheries surveys mainly for the purpose of obtaining information on the population structure. Where age determinations are possible the length data are associated with the age data to separate the total fish population into year classes, or possibly into cohorts.

Recorded length measurements are often a major part of the results collected during a resource survey. As these are so important it is necessary to have well designed documentation both for recording at sea and for later processing. Figures 13 and 14 give illustrations of different forms designed to satisfy varying needs for different species. In this fishery there are about ten species which are examined in detail and where large samples are taken. Each major species is recorded on a separate differently coloured coding sheet with related species recorded on the front and back of the form. A prepared scale which will cover all possible length measurements for these species is included in the form. For some species the class interval is 1 cm while for small species such as many of the pelagics a class interval of 0.5 cm is employed.

It is necessary prior to a survey to define what length measurement is required for each species, e.g. total length or fork length, and also the length class interval. In

HADDOCK 1 2

Haul No. /

Large/Small Mesh

CM	OTO	Measured					Raised Total
5							
6							
7							
8							
9							
10							
11							
12							
13							
14							
15							
16							
17							
18							
19							
20	2					2	7
21	15	1		9		14	48
22	15	HHH		32		37	127
23	15	HHHH		43		48	165
24	15	HHHH		41		46	158
25	15	HH		22		27	93
26	15	H		12		17	58
27	15			3		8	27
28	4					4	14
29	3					3	10
30							
31							
32	3					3	7
33	15			1		6	14
34	15			3		8	19
35	15	H		12		17	41
36	15	HHI		25		30	72
37	15	HHH		32		37	89
38	15	HHHH		40		45	108
39	15	HHHHI		47		52	125
40	15	HHHH		40		45	108
41	15	HHH		32		37	89
42	15	HHI		28		33	79
43	15	HH		22		27	65
44	15	H		11		16	38
45	15			3		8	19
46	14					4	10
47	3					3	3
48	2					2	2
49	1					1	1
Total	122			458		580	1596

CM	OTO	Measured					Raised Total
50	2						2
51	1						1
52	2						2
53	3						3
54	2						2
55	1						1
56	1						1
57							
58							
59							
60	2						2
61							
62							
63	1						1
64							
65	1						1
66	1						1
67	1						1
68							
69							
70							
71							
72							
73							
74							
75							
76							
77							
78							
79							
80							
81							
82							
83							
84							
85							
86							
87							
88							
89							
90							
Total	18						18

Comments:

SUB TOTALS

20 - 29 cm 206

32 - 46 cm 368

GRAND TOTAL 1614

	1st Sample	2nd Sample	3rd Sample
Counted (not measured)	148	136	—
Range of fish counted	20-29	32-46	≥ 47
Fraction Sampled	2/4	4/7	ALL

Figure 13. Form for recording haddock length composition (1 cm intervals)

Haul No. /

NEPHROPS

Large/Small Mesh

	Males				MS	Total	Females				FS	FB	Total
10													
11													
12													
13													
14													
15													
16													
17													
18													
19													
20													
21													
22													
23													
24													
25													
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45													
46													
47													
48													
49													
50													
51													
52													
53													
54													
Total													

	M	MS	F	FS	FB	Total
55						
56						
57						
58						
59						
60						
61						
62						
63						
64						
65						
66						
67						
68						
69						
70						
Total						

Grand Total

First Sample

Counted (not measured)

Range of Nephrops counted.

Fraction Sampled

Second Sample

Counted (not measured)

Range of Nephrops counted

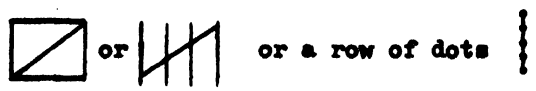
Fraction Sampled

Comments:

Figure 14. Form for recording Nephrops length composition, by sex, and condition. (1 mm intervals)

statistics a class interval is usually categorised by its mid-point, i.e. the interval 10.0 cm to 10.999 cm has a mid-point of 10.5 and this is the value which is used to calculate the mean length from the frequency distribution. In fisheries statistics it is usual to have a class interval of 1 cm from say 11.0 cm to 11.999 cm but this is defined as 11, i.e. the lower limit of the class. There are very good reasons for doing this as classes defined in this way are more readily combined than classes which have non-integer end points. The most important point is that all personnel should be aware of the class interval which is employed as a standard and that measurements should be taken accordingly. Many regional organisations have adopted standard methods of taking and recording length frequency data to facilitate the collation of information from different countries or institutes. These standards should be observed by all countries in that region so that all analyses are done on compatible measurements.

It is essential, too, to standardise the methods of recording frequencies from individually measured or counted fish. There are several methods used, e.g.



and a line drawn through them when a fifth observation is taken. Each system has its merits but the last allows many more observations to be made in the limited space provided on the form; and joining two sets of five into an H form thus

makes it simple to add up the numbers in tens. These specimen forms were designed with the last method of recording in mind and the vertical lines assist in sectioning off the recorded dots.

On many occasions it is not possible to measure all fish taken during a haul and sub-sampling has to be done. In section 2.8 the procedure for selecting a sub-sample of the catch was described. The importance of random selection of sub-samples for measurement cannot be too highly stressed. Taking a few fish for measurement from a catch in a pile on deck is highly dangerous because most people will tend to pick the larger fish which will in turn give a highly biased estimate of the size frequency distribution of the population. As described in section 2.6, in relation to allocating fishing positions within a survey area, one can also gain considerably in the precision of one's estimate of the size frequency of the fish in a catch by stratifying the samples of fish to be measured. So it is best when one has to sub-sample for length measurement, and when there is a considerable range in size within the catch, to first sort it into baskets by size groups. One then picks the required number of baskets within each size group, at random, for measurement. The number of fish in each length interval in the total catch can then be calculated by multiplying the number measured in that size interval by the appropriate raising factor. Suitable recording documents will make provision for this. Figure 13 gives an illustration of a fairly complicated recording. The quota for otoliths was five per cm length class and these have been taken whenever possible and recorded. The fish caught were in three size groups, (a) 20-29 cm (b) 32-46 cm (c) above 46 cm. Within the available time it was not possible to measure all the fish so, after the fish were selected by size into several baskets, two baskets out of the four in the length range less than 30 cm were examined. Of these fish 103 from each basket examined, were measured (of which 44 were otolithed) while 74 per basket examined were counted only. Similarly in the length range 32-46 cm, four baskets out of seven were examined and 92 per basket were measured and 34 per basket counted. Above 46 cm all fish were measured. The recording of this information has been done systematically, and each part of the length range can now be raised appropriately and verified, as all the information is there. For example in the

haddock sample shown in Figure 13, there were 37 fish 22 cm long measured, of which 5 were also otolithed. In the 20-29 cm size category a total of 206 fish were measured and 148 counted from 2 baskets out of a total catch of 4 baskets of this size category. Therefore the total catch of this size category was 2(206 + 148) = 708 fish. The raising factor for the size frequency distribution of the fish measured in this size category is therefore

$$\frac{708}{206} = 3.437.$$

Multiplying the measured size frequency distribution given in column 1 of Figure 13 by this factor, for sizes between 20 and 29 cm, gives the Raised Total given in column 2. Similarly for haddock in the size interval 32-46 cm the raising factor is

$$\frac{7/4(368 + 136)}{368} = 2.397$$

and for this size category multiplying column 1 by the raising factor gives the frequencies in column 2. There was no sub-sampling of fish greater than 46 cm, so the frequencies of these require no raising factor. The RAISED TOTAL column now contains the estimate of the length frequency distribution of haddock caught in that haul and the GRAND TOTAL contains the total number of fish caught. This information can easily be checked and the RAISED TOTAL column is the required information which can now be further processed or combined with data from other hauls. It is worthwhile noting here the sub-totalling procedures whereby the total calculation is broken down into small parts each of which can more readily be checked by the officer responsible for verifying the data. As many of these calculations are done under conditions where elementary errors are easily made, checking procedures of this kind should not be disregarded.

As another illustration, Figure 14 is designed to record data on Nephrops norvegicus, which is measured in millimetres. Here, information is required for males and females separately and also for soft males (MS) and females (FS) and berried females (FB). Most of the Nephrops caught are in the range 10-54 mm but provision is also made for the smaller numbers likely to be caught in the range 55-70 mm. If a measurement over 70 mm was taken this could be included in the COMMENTS column, where also other observations can be made.

The important point of such forms is that planning them, and having them prepared in advance of going to sea, not only reduces the work to be done there but also ensures that the data are collected and recorded in a standard way on all cruises, that all the essential data for relating the sampling to the catch from which it was taken are recorded, and that all the details of the sub-sampling procedure are given so that the sub-samples can be raised to the total catch. Without such detailed and systematic recording it can be difficult to be sure that apparent differences between stations or between surveys are real differences.

5.7 Biological Data

On many cruises detailed biological information is collected from samples of the fish caught. Again the sample should be taken in such a way that it is representative of the total catch or can be raised to an estimate representative of the total catch. Details of sampling procedures are discussed in section 2.8 and the main aim here is to provide an illustration of how the data which are collected can be recorded systematically, so that they can be collated with the appropriate catch data at the later analytic stage.

The Biological Sampling Sheet given as Figure 15 illustrates a method of recording detailed information on individual fish. The heading information viz. species, vessel, name, etc., are all necessary to link this sample with the other catch data of which this may be only a small sample. It is also necessary to link this information with specimens preserved for more detailed biological analysis which is perhaps necessarily done on shore at the end of the cruise.

This specimen document allows length, weight, sex, maturity and age data for each specimen to be recorded and also specifies the units of measurement where appropriate. It is also designed to follow the natural sequence of observation, i.e. the fish is measured first then weighed, its sex and maturity are recorded and the scale or otolith sample taken to be preserved for examination at a later time.

The requirements of this form are self-explanatory and provision has been made for recording other information which may be considered necessary. In addition, space has been left for adding general observations to qualify the actual recordings made.

5.8 Recording Acoustic Data

Recent advances in acoustic techniques permit the acquisition of very large volumes of data which may be recorded on some magnetic medium such as a tape cassette or cartridge, or which may be summarised by digital read out from a computer. However, it is still necessary in many instances to record information from less sophisticated echo sounder surveys in a way which will provide some quantitative assessment from the area surveyed.

Figure 16 illustrates the type of information which could be recorded during an echo sounder survey. This provides a record, at fifteen minute intervals, of the information recorded on a sounder. It is, of course, difficult to quantify exactly the traces given by an echo sounder, but prior to a cruise, staff should be trained in recording typical traces possibly from photographs of several examples which occur frequently (see Chapter 3 and Forbes and Nakken 1972). This should help to make the observations as compatible as possible from observer to observer.

This document, which was proposed for a regional fishery survey in the Arabian Gulf, between Iran and the Arabian peninsula, requires information to be regularly recorded, summarising events over 15 minute intervals. Most of the information is self-explanatory and should be compatible with that recorded in other cruise documents. In particular the sounder make, type and frequency should be recorded and as far as possible constant settings which have been decided prior to the cruise should be used and recorded. The definitions given for recording the less obvious items are:

a) Schools - these are dense discrete groups of echo recordings in which individual fish cannot be distinguished.

b) Scattering layer - a more or less continuous layer of echo recordings in which individual targets may or may not be distinguishable.

c) Single fish - single targets which are not grouped into schools or layers.

d) Number - counts of schools or single fish observed during a 15 minute recording period.

e) Extent - the length of the echo trace on the paper recording should be measured in millimetres.

f) Depth - the average and the upper and lower depth limits should be recorded in metres.

g) Type - identification of the grade of scattering layer when a scale for typical recordings has been decided (see section 4.3.1.2).

Regional Fishery Survey and Development Project (REM/71/278)

BIOLOGICAL SAMPLING SHEET

Vessel Name

Species Name

vessel code	cruise number	station number	sample number	day	month	year	Species code			Stratum code				sheet number	sample weight (kg)									

Fish Number

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25

Length (mm) Other ( )

Weight (gm) Other ( )

Sex (Male=1, Female=2)

Maturity

Age (Otolith, Scale)

Fish Number

26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50

Length (mm) Other ( )

Weight (gm.) Other ( )

Sex (Male=1, Female=2)

Maturity

Age (Otolith, Scale)

Form Code REM/278/6

Figure 15. Form for recording biological data on individual fish

Regional Fishery Survey and Development Project (REM/71/278)

ACOUSTIC LOG SHEET

Vessel name:

Sheet of

Vessel code	Cruise number	Day	Month	Year	Lat.		Long.		Course	Speed	Sounder								Time zone relative to G.M.T.		Sheet number
					°	'	°	'			Make		Type		Freq.		Depth range				

Time local	Log	Bottom depth (m)	Schools				Scatter, layer				Single fish				Notes Observations on traces Presence absence type etc.
			Number	Ext. (mm)	depth (m)		Type	Ext. (mm)	depth (m)		Number	depth (m)			
					From	To			From	To		From	To		

Form code: REM/278/4

Figure 16. Form for recording acoustic data

REFERENCES

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6. DATA ANALYSIS AND REPORTING

In the previous chapters an account has been given of the techniques available for resource appraisal surveys, with indications of the circumstances under which they are applicable, and guidance as to how these techniques should be applied. These chapters dealt with what data should be collected, and how to collect and record it. We are now concerned with how these data should be used to provide the answers required from the survey, and how the results should be passed on to those who will use them to direct the future development of the fishing industry.

In Chapter 1 the objectives of a fishery resource appraisal survey were defined as assessing:

1. the species of fish available in the area;
2. their spatial distribution within the survey area and how this varies seasonally;
3. the catch rates that could be achieved, and how these vary seasonally and from place to place within the survey area;
4. the size of the resource;
5. the annual sustainable yield which can be taken from it.

For the administrator or investor considering the development of a new fishery, or expansion of an existing one, the key questions are:

(a) will the new vessels which are required catch enough to cover their operating and capital costs?

(b) what is the total potential catch which in turn governs how many vessels will be required and how big the investment should be in port facilities, processing factories, etc.?

(c) what effect will the additional vessels have on the fish stocks, and hence on the catches of existing vessels?

The first question is always believed to be the key question in fishery development, as indeed it is to the individual investor. For the government administrator it can be a highly misleading one; to him the important question is the net addition to the total catch, or total national economy, i.e., the marginal yield of the new vessel. This is always less, and usually much less than its actual catch in all but the most lightly fished stocks (Gulland, 1968).

The answer to the first of these questions is dependent on the data to be provided from objectives 1-3 above. Objectives 4 and 5 will provide the data from which an investor or administrator will make his decisions on the second and third of these questions.

We shall now look at how one provides answers to each of these questions using the data collected during the survey operations.

6.1 Species Available and Their Seasonal and Spatial Distribution

In analysing the results of the survey, objectives 1 and 2 can be conveniently considered together as, to a large extent, they are different facets of the same parameter, namely an index of the relative abundance of fish on the grounds surveyed. The species of fish available could, of course, be simply listed by extracting from the catch records all species which have occurred on one or more occasions. Although such a list might be of interest to scientists, it would be of very limited value to those interested in developing a fishery. Isolated captures of single specimens do not form the basis of a fishery. So

more quantitative records are required. Similarly the spatial and seasonal distributions within the area surveyed should be expressed in quantitative terms which will allow decisions to be made as to whether the area can support an economic fishing industry, and if so on what species, over which months of the year, and in which parts of the total area such a fishery is likely to be most profitable.

Although some indication of the answers to these questions may be obtainable from indirect methods and from acoustic surveys, the most directly applicable data are likely to be those obtained from fishing surveys. These can be expressed in terms of catch per unit effort which, if the effort unit is appropriately chosen, is an index of the population abundance in the area fished at the time when the fishing was done. Provided the fishing effort during the survey has been properly distributed in space and time, as discussed in Chapter 2, the results from fishing surveys expressed as catch per unit effort can therefore give a measure of the relative abundances of species within the area and of how these vary seasonally and spatially. Two factors, however, must be remembered in the interpretation of such data from resource appraisal surveys: (a) it is unlikely that such a survey, using a single type of standard fishing gear, will sample all species of fish in the area surveyed - for example where all sampling is done by demersal trawl, pelagic species will be poorly represented, if taken at all; (b) even within a single category of fish, such as demersal species, the catch per unit effort of the different species will be a different function of the population abundance, depending on the availability and vulnerability of the species to that gear. For example a low headline demersal trawl is likely to catch a larger proportion of the flatfish in its path than of the round fish. However, although such factors are likely to provide some bias in estimates of relative population abundances between species they are not likely to seriously bias estimates within a species of either the variations in abundance between seasons or between areas.

In practice, to answer questions on the variation between seasons or between areas in fish abundance, the best measure, at least for demersal trawl surveys, is likely to be the catch per hour, or some other unit of time, fishing. This can be readily calculated, for each haul taken on a cruise, from a recording sheet such as that shown in Figure 12 and mean values calculated to give a measure of the catch per unit effort within a season or within an area by appropriate groupings of the individual hauls.

For pelagic species the best measures of variations in abundance, between areas and seasons, are likely to be obtained from acoustic surveys, with fishing by suitable gears to identify the species giving the returned echoes. Where the topography of the grounds or the behavioural characteristics of the species make it necessary to use other methods, such as traps, gill nets, etc., the data can be treated in the same way as for demersal trawl using unit of gear shot as the basic effort unit.

6.2 Estimation of Potential Commercial Catch Rates

The question of what catch rates are likely to be achievable by a commercial fishery is of over-riding importance in deciding whether a new fishery should be developed or not. Catch rates can be estimated directly only from prospecting surveys. A first estimate may be obtainable from fish concentration measured by acoustic surveys, and comparison of catch rates obtained from similar concentrations in other areas. But such estimates are likely to have very wide confidence limits because of differences in catchability between species, and within species between areas. The results of prospecting surveys should again be expressed in catch per unit effort. Although for demersal trawl catch per hour fishing is probably the best unit of abundance to use in measuring seasonal and spatial variation in population density, it may not be a measure of catch rate which is meaningful to the needs of the fishing industry, or to fisheries administrators who are trying to assess the economic viability of a potential fishery. For this purpose catch per day's absence from port, or absence over some longer time period, may be more appropriate. Data of this type are not readily obtainable from the results of a resource appraisal survey because survey vessels will normally be changing grounds frequently, and making fewer hauls per day at sea than a commercial vessel. This can be corrected for if the likely number of hours

fishing per day at sea by a commercial vessel can be estimated from records of similar commercial vessels operating in other areas.

A greater bias in extrapolating from research vessel to commercial vessel results is likely to come from the fact that in a commercial fishery the fleet will locate above average concentrations of fish and continue to fish on them until the catch rate declines; on a resource appraisal survey the fishing positions must be distributed at random in relation to fish abundance at least within the defined strata, as discussed in Chapter 3, and the ship will do a fixed number of hauls at each position irrespective of the size of the catch. Furthermore the gear selected for a resource survey is likely to be a multi-purpose one which will catch, reasonably efficiently, as many species of fish as possible. In a commercial fishery modifications are likely to be made to the design, or rigging, of the gear which will increase its efficiency in catching the species which gives the best economic return. But conversely these modifications are also likely to decrease its efficiency in catching some other species. Finally because of different demands on the time of, and in the motivation of, the crew of a survey vessel, it is very difficult to translate its performance, even with regard to fishing time, to what is likely to be achieved by a vessel fishing commercially. For these reasons although a resource appraisal survey will give a first estimate of likely catch rates of a commercial vessel, it will be a rather imprecise one and it may be desirable to mount a separate project to establish these more precisely, if the first indications suggest that developing a fishery is likely to be only marginally economic.

The catch of a fishing vessel is a function of: (a) its fishing power, (b) the time that it spends fishing, (c) the density of fish on the grounds it fishes. In translating catch rates from a survey into an estimate of the catch rates likely to be attained by a commercial fishery it is perhaps best to look at these three parameters separately. As far as possible the survey vessel should be similar in engine power, size, and gear handling characteristics to the type of ship envisaged as being used in any fishery development. Studies made on fishing powers of demersal trawlers suggest that it increases linearly with engine horsepower and with gross tonnage. So even if the survey vessel is different in some respects, some extrapolation can be made, provided the discrepancy between the survey vessel and the projected fleet is not too wide. Similarly for lines, traps, and gill nets fishing power is largely a function of the number of units of gear which can be handled, and again a correction to the survey results can be made on this basis. For pelagic fishing gears, such as purse seines and pelagic trawls, the problem is rather more complex. For these there seems to be a critical size, or towing speed, below which the catch falls off very sharply. So extrapolation to smaller, or lower powered, vessels and gear sizes may in those cases be highly misleading. A number of useful papers on problems in measuring fishing effort can be found in Pope (1975).

Fishing time can be fairly easily corrected for provided proper records are kept of the time the survey vessel spends in fishing, and provided data can be obtained of the likely time which will be spent fishing by the commercial fleet. The latter can perhaps be obtained from the performance of similar vessels operating in other areas which are comparable in respect of weather, fishermen's behaviour patterns, etc.

Differences in fish abundance on the grounds are likely to cause the greatest problems in extrapolating from the results of a resource appraisal survey to the operations of a commercial fleet. As discussed above this is because the commercial vessels will rapidly learn to concentrate their fishing effort on the most productive grounds and adapt their gear to maximise their catch rates of species which give the best economic returns. Any assessment of this from a survey vessel is likely therefore to be rather imprecise and to be below the value which will be achieved in commercial practice. However the best approximation which can be made from such survey data will probably be obtained by looking at the frequency distribution of the survey vessel catch rates and taking the mean of the top half of the range in a survey which has been carried out to directly assess catch rates or the of the top 10-20 percent of the distribution in the case of a resource appraisal survey.

It must always be remembered, and must be pointed out in the final survey report, that the catch rates obtained during the survey refer to a virgin, or lightly exploited, resource. As a fishery develops the abundance of the stock, and thus the catch rates which will be taken by a vessel of constant fishing power, will decline. Following the simple Schaefer model the maximum sustainable yield is taken when the stock is reduced to one half of the virgin biomass. Thus when the stock is being fished at the maximum potential yield the catch rates will probably be about half of those attained at the start of the fishery.

6.3 Standing Stock Size

The methods of estimating the size of the stock in an area from egg or larval surveys, and from acoustic surveys have been fully discussed in chapters 3 and 4. In this section therefore we shall consider only the estimation of population size from exploratory fishing surveys.

From such fishing surveys using the type of gear appropriate to the species in question, for example, lines, traps, pelagic trawls or purse seines, it may be possible to get a relative measure of population size which is useful in estimating changes in abundance with time. However for such gears it is not possible to convert these catch rates to absolute abundance, either because the area sampled by them cannot be measured - for example for lines or traps; or because, as in the case of pelagic gears, it is not practicable to sample in a three dimensional space with sufficient intensity to produce an estimate with acceptable confidence limits.

For demersal trawls, however, it is possible from the results of a properly planned survey to get at least an acceptable first approximation to the likely population size; or at least of that part of the population which is available to, and vulnerable to, the trawl. The first requirement for doing this is to convert the catch taken in each haul into an estimate of the abundance of fish per unit area where this catch was taken by calculating the area swept by the trawl.

Once this is known, then the density of fish, that is the weight per unit area in area j (D_j) is given by:

$$D_j = C_j/(q_j a_j) \qquad \text{.....1}$$

where q_j is the catchability coefficient (Paloheimo and Dickie, 1964) that is the proportion of fish in the area swept by the trawl which are caught by it

C_j is the catch in weight taken in hauls in area j

a_j is the area of bottom swept by the trawl hauls made in area j.

If the total area of sea bottom in area j is A_j then the weight of the fish population P_j in that area is:

$$P_j = \frac{A_j C_j}{a_j q_j}$$

This procedure will give only an approximation to the true population size for a number of reasons: (a) the area effectively swept by the trawl is not easily estimated; it is likely to be greater than the product of the distance over which it was towed and the spread from wing tip to wing tip because of the herding effect of the sweeps but is likely to be less than the distance towed multiplied by the distance between the trawl doors because the sweeps are not likely to be 100 percent effective in herding; (b) q_j is also difficult to estimate because it is an amalgam of several factors. In the first place it must correct for that proportion of the population which is not available to the trawl because it is distributed above the headline, or buried in the sea bed beyond the effective range of the footrope. Secondly it must take account of the fact that all of the fish within the volume actually swept by the trawl will not be captured because some take

evasive action. Thirdly, all of the fish which enter the trawl mouth will not be retained because of mesh selection.

As a first approximation one can assume that q_j is equal to 1.0 to give a lower limit of the size of that proportion of the stock which is large enough to be retained by the trawl. For fish of a size smaller than this, but within the selection range, a correction can be made to allow for escapes through the meshes from a knowledge of the selection parameters. It should be noted that since q_j is unlikely to be as high as 1.0 this will always give some under estimation of the stock and every opportunity should be taken to refine this estimate of q_j from any knowledge available on the vertical distribution of the species under consideration, and of its behaviour in front of a trawl. For example, useful information may be obtained on the occurrence of fish above the headline of the trawl by running the echo-sounder during trawling operations.

It will be noted that in equation 2 above the assumption is made that the abundance of the stock, within the area a_j swept by the trawl, is an unbiased estimate of the abundance per unit area over the whole of area j (A_j). In this context it is therefore important to pay particular attention to the advice given in Chapter 2 on selection of trawling positions. The precision of the estimate P_j will also be dependent on the variance of the estimate of the abundance in a_j and therefore the advice on stratified random sampling given in that chapter should be followed to reduce the random error of the estimate. If such a stratified sampling scheme is followed the estimate of the population over the whole of the survey area is most accurately calculated by estimating P_j for each sampling stratum and summing them. Then, if one has n strata in the total survey area the estimated population weight in the area is $\sum_1^n P_j$ =

$$\sum_1^n \frac{A_j\, C_j}{a_j\, q_j}$$

and the variance of this estimate will be

$$\sum_1^n \text{var } C_j \left(\frac{A_j}{a_j\, q_j}\right)^2$$

It should be noted that the advice given in Chapter 2 on choosing alternative positions for trawling in the event of one or two of the pre-selected positions being unworkable because the bottom is too rough, will not affect the accuracy of the estimate provided the number of such positions is small. If, however, a major part of one of the strata proves impossible to trawl in one would be likely to get a very biased estimate of the abundance in that stratum by trawling only in the small area where this is possible and weighting the resulting catches by the total area of the stratum. Instead, if a large part of a stratum is untrawlable, all one can do is to weight the catch from that stratum by the area which is trawlable and accept the fact, and make it clear in the report that one's estimate of the total population is underestimated to some extent by the omission of the untrawlable area.

6.4 Estimation of Potential Yield

In practice an estimate of stock size, as so many tons of a species present in the survey area at one period of time, is unlikely to be of much interest to the non-scientists who commissioned the survey. The administrator, or someone who is considering investing in developing a fishery, really wants to know what the potential sustainable yield is from this stock, in other words how much they can expect to take from it each year on a long-term basis. This is determined not only by the absolute size of the exploitable resource but also by its turnover rate. The latter in turn is dependent on the life-span of the individual fish and the rate at which those dying are replaced; the shorter the life-span and the quicker the replacement rate the higher the proportion of the stock which can be taken from it as catch.

The estimation of the size of the standing stock therefore is for most practical purposes an intermediate step in estimating the annual sustainable yield. In the case where a stock is not yet being exploited commercially this can be calculated from survey estimates of the virgin stock biomass. In Gulland (1970) it has been shown that if one starts with either the simple Schaefer (1954) model, in which the maximum yield is reached when the biomass is reduced to half the virgin level, or uses the Beverton and Holt constant recruitment model the maximum sustainable annual yield (Y_{max}) can be estimated as:

$Y_{max} = 0.5\ M.B_o$ where M = natural mortality rate and B_o = the virgin (unexploited) biomass of the exploitable stock.

To calculate the yield from this equation demands not only an estimate of the size of the virgin stock, which can be obtained as described in the preceding section but also an estimate of the natural mortality rate of this stock. This can be obtained from a variety of sources - from the relationship between natural mortality and maximum age in the virgin population (Figure 17); from the relationship between M and the growth coefficient K (Beverton and Holt, 1959), from the natural mortality rate of a closely associated species whose natural mortality rate is known, or from a catch curve (Baranov, 1918) derived from biological sampling of the virgin population.

The relationship between maximum age and natural mortality rate shown in Figure 17 is perhaps the easiest of these methods to apply as it demands no more than projecting from the age of the oldest fish, of the species in question, encountered during the survey to the regression line and reading off the corresponding natural mortality rate on the Y-axis. For example, using this relationship a population with a maximum age of 10 years would have an estimated natural mortality rate of about 0.25. However, the maximum age on the X-axis is the greatest age which the fish in the population reach and fish of this age may not be represented in the survey catches, either because they are distributed outside the surveyed area or in a different depth stratum to that fished by the gear used or because of lower vulnerability to the gear used. Also, the oldest fish will be very rare and therefore may be absent from the survey catches owing to chance alone.

Beverton and Holt (1959) have shown that within certain groups of fish (clupeoids, gadiforms, salmonids, pleuronectoids) there is a roughly linear relationship between the natural mortality rate and the growth coefficient K of the Bertalanffy growth equation. Having a known K value for a species within one of these groups, one can accordingly get an estimate of the likely M value. However, this method is likely to have rather limited application in survey assessment because the majority of the species encountered will often be outside the groups for which the relationship is known and because in only a few cases will there be sufficiently accurate estimates of the K value appropriate to that species.

In an unexploited population estimates of the abundance of successive age groups at any one time, for example estimates of their abundances in one year or of their mean abundances over the same period of several years can be used to provide an estimate of the natural mortality rate provided there is not too great variation in year-class strength. To try to minimize the effects of year-class strengths on the mortality estimate the best technique, particularly when the abundance estimates are based on only a short period of years, is to plot the abundance estimates of age groups on semi-logarithmic paper against the corresponding ages in years. A straight line is then fitted to the points and the slope of this is an estimate of the mortality rate. As the stock is unexploited this is equivalent to the natural mortality rate. The abundances of age groups used in this plot can be either absolute values, obtained as discussed in section 6.3, or mean catch per unit effort values. The only thing that matters is that they are in the same units for all age groups.

Figure 18 shows a set of artificial data of this sort. The abscissa is designated "age or time" because the abundance indices on the ordinate could refer either to the same year-class in successive years or to all the fully recruited age groups present in the catch in

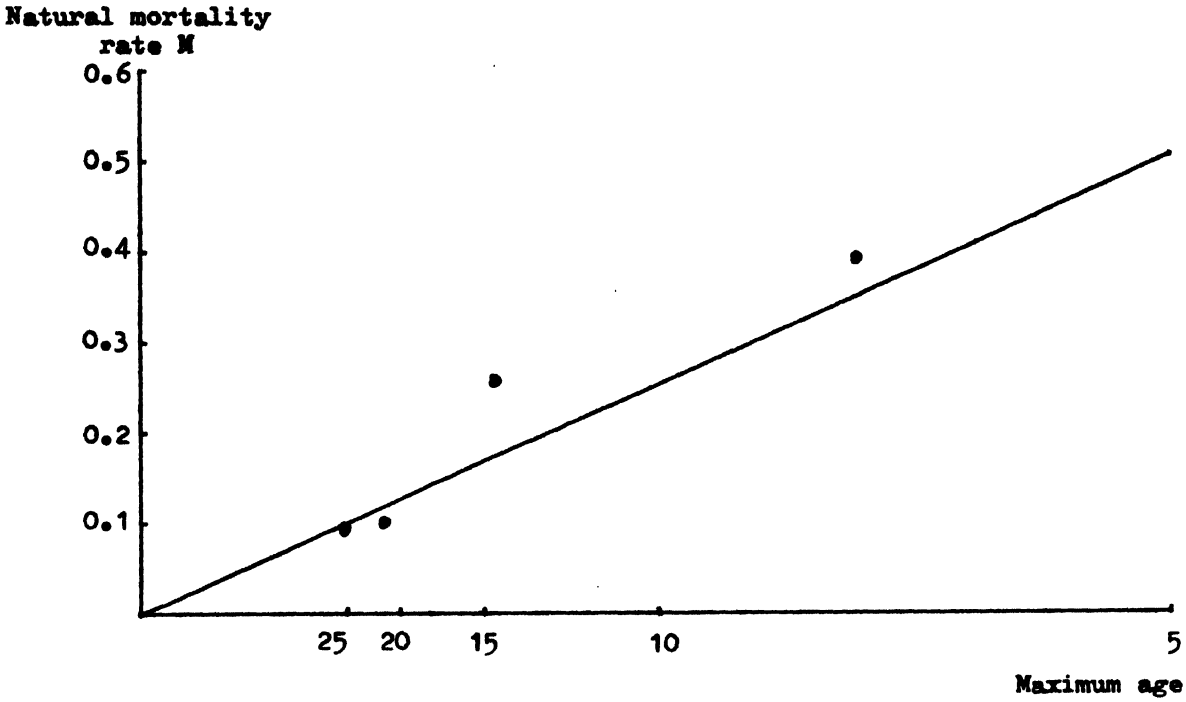

Figure 17. Relationship of natural mortality rate M to maximum age. (From Tanaka, 1960)

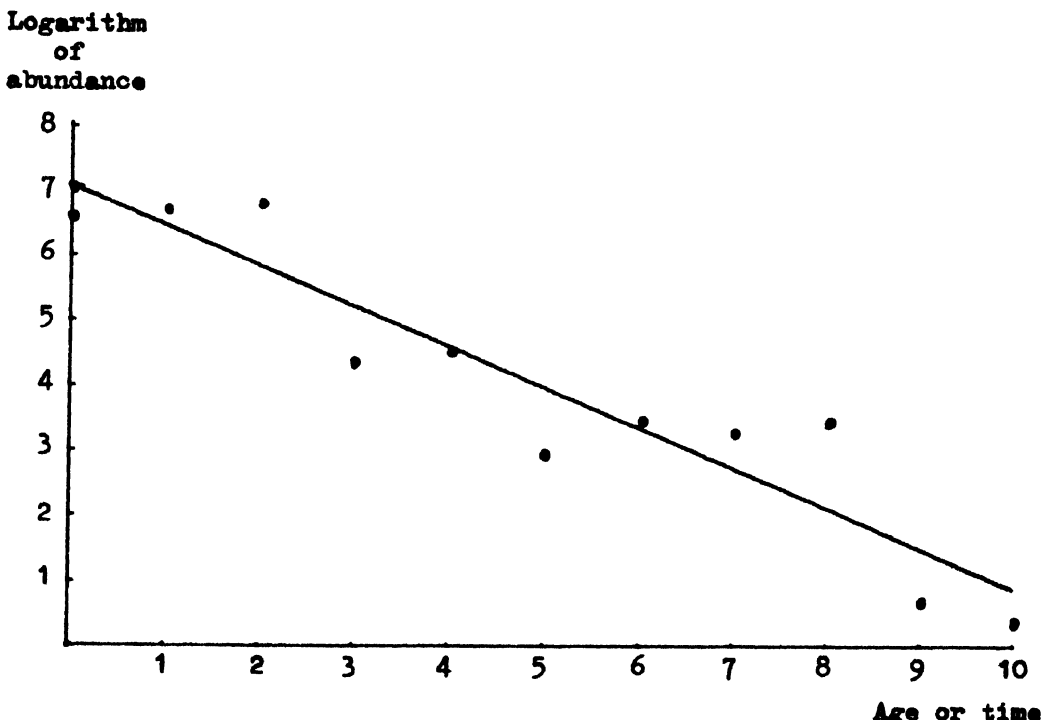

Figure 18. Estimation of M from a plot of the logarithm of abundance against age or time

one year. Age groups not yet fully recruited would appear as anomalously low values on the left-hand part of the curve; where such values appear, they should of course not be included in the regression. In this case the fitted regression line has a slope of -.62, so the estimated instantaneous mortality rate is .62. The standard deviation of the estimate is .25, large but not unusually so for this method.

Estimates of natural mortality from any of these sources are likely to be rather imprecise. Allied to the lack of precision in the estimate of the virgin stock biomass, discussed in the preceding section, this will result in the estimate of sustainable yield from the Schaefer equation being indicative of a likely order of magnitude rather than an accurate figure on which long term planning should be based. However, even such a rough estimate would probably be sufficient to show whether there is the potential for initial development of a fishery, and on what scale plans for medium term development should be made. Once a commercial fishery is started, estimates of sustainable yield can be refined using the much greater sampling capability of the commercial fleet and the analytical models of Beverton and Holt (1957). The subject of assessment from such data is outside the scope of this manual but a good introduction to it will be found in Gulland (1969).

6.5 Presentation of Results

It has been repeatedly stressed throughout this manual that resource appraisal surveys are mounted with the practical objective of assessing what resources are available in the area, what catch rates can be achieved by fishing them, and what annual yield can be taken as a guide to those who are interested in developing a fishery. However good the answers to these equations, the survey will not achieve its objectives unless the results are made available as quickly as possible, and in an understandable form, to the people who will act on them, be they administrators, fishing companies, or fishermen.

Different users are likely to require different types of reports. If there is already some fishing industry in the area, even at a low level of development, information obtained on high catch rates within the fleets' range of operation should be transmitted to it by the quickest possible means, before the distribution changes, or the concentration disperses. For the administrator and the fishing industry which is contemplating investment regular progress reports are desirable as a guide to the planning of their investment, even if the answers are at that stage somewhat tentative.

The final report, which will contain a detailed analysis of seasonal and spatial distributions and estimates of stock sizes and potential yields, can be prepared only after the sea work has been completed. The time lapse between completing the sea work and submitting this report, however, should not be unduly increased by searching for more refined estimates. Otherwise investment may have gone ahead too fast for the resource to be capable of supporting it, or alternatively potential investors may lose interest. Finally the reports should be prepared in as attractive and readable a form as possible, an adequate number of copies produced, and those distributed to all of the potential users.

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7. CONCLUSIONS AND GENERAL CONSIDERATIONS ON CHOICE OF SURVEY METHODS

Fisheries resource surveys are conducted with the practical aim of providing the sort of information needed to make sound decisions on whether to start a new fishery on a resource which is not being fished, or to develop further a fishery which is currently only exploiting the fringe of the distribution of a resource. The two major questions which arise in making such a decision and which a resource survey can answer are:

(a) are the catch rates of the ships which will be required for the new or expanded fishery likely to be high enough to make the fishery economical? Included in this question are such factors as the species composition of the catches, the distribution of the fish within the survey area, and how the distribution and the catch rates vary seasonally and from year to year. All of these have an appreciable impact on any assessment of the economic viability of a fishing fleet and on a decision as to where the fleet should be based.

(b) what is the long-term annual sustainable yield of the resource likely to be? The answer to this is vital in deciding how big a fleet will be required to exploit the resource and on what scale the infrastructure of harbour facilities, processing facilities and distribution network for the final product will be required.

As has been stated earlier therefore the questions which the survey has to answer are:

(1) what type of fish are available in the area?

(2) what is their distribution within the area and how does this vary seasonally and from year to year?

(3) what catch rate can be made and how does this vary seasonally and within the area?

(4) what is the size of the resource and what annual catch can be taken from it on a sustained basis?

Before any survey is planned to answer all or any of these questions as full a review as possible should be made of what is already known of the ecology of the area and of the fish stocks in it and in adjacent areas. It is in this context that the indirect methods discussed in Chapter 4 are likely to have their application. Any data already available on primary production, secondary production, abundance of fish eggs and larvae or food of higher trophic forms should be utilized to make a first rough estimate of the likely size of fish resources in the area in question. These data and other non-fishery information can be particularly valuable in indicating whether or not there are likely to be large year-to-year differences in the distribution or abundance of the fish stocks. It may be that such data would suggest the area has little potential for fishery development, in which case this should be brought to the attention of the body which is authorising the survey. They may then decide not to proceed with the project - that decision is theirs but they should make it in the light of the best available information. In most circumstances it is not advised that the collection of data appropriate for application of any of the indirect methods should play a major part in the survey operations.

Although a "resource appraisal survey", as defined in Chapter 2, can provide some estimate of likely catch rates, they are normally rather imprecise and often biased estimates. If the estimates from this source are clearly well above, or well below, the level required for economic viability of the fleet such estimates would be quite adequate. However, if the level required to make a fishery economical falls within the confidence limits of such estimates, or is just outside them, it would be advisable to mount a prospecting survey to get more adequate measures of catch rates. The essential point is that resource appraisal surveys and prospecting surveys, because they demand quite different survey strategies, are not completely compatible. Resource appraisal surveys by appropriate usage of the data, can provide some rough estimate of catch rates which may, or

may not, be sufficient to make a decision on the initial development of a new fishery; prospecting surveys can never produce usable estimates of either the relative or absolute size of a resource and of the sustainable yield from it.

So, in the early stage of survey planning a decision will have to be made as to which of the two objectives, assessing catch rates accurately or assessing the potential yield, greatest priority should be given. This is a decision which will largely rest with the body authorizing the survey but the biologist who is to be responsible for it should explain the options, and their consequences, fully and objectively. Normally a resource appraisal survey will give answers to more of the basic questions which are likely to arise but if this option is chosen it should be pointed out that it may be necessary to mount, in addition, a prospecting survey which can then probably be done with less input of effort because the information collected on the appraisal survey will be utilized to guide its design.

If it is agreed to undertake a resource appraisal survey, the survey method to be used must be decided. Again this should be done in the light of what information is available of the exploitable stocks available in the area - for example, are they entirely or predominantly pelagic or demersal and if they are demersal, are they distributed on ground which is suitable for or too rough for trawling? If the information available is inadequate to make a decision on the most appropriate survey technique, some pilot study should be carried out immediately, for example by doing a quick acoustic survey over the area combined with trawling on areas of suitable substrata to assess the distribution of suitable trawling grounds, what fish and in what abundance are available on these grounds and what is the distribution of fish off the bottom.

If in the light of available data, or of the results of a pilot survey, it is decided that the major resource is demersal fish and the area is generally trawlable, a fishing resource appraisal survey using a demersal trawl will be most appropriate. Except for acoustic surveys using sophisticated equipment in favourable circumstances, this is the only method which will supply a measure of the absolute abundance of the resource and hence of the sustainable yield from it. To get such a measure from a trawling survey, and to get adequate measures of species composition, and variability in abundance over the area and between seasons, it will be necessary to cover the whole of the area with trawling stations distributed as advised in Chapter 2 and repeat the survey as frequently as possible at different times of the year. It must also be stressed that for resource assessment such a survey must cover the <u>total distributional area of a stock</u>. If part of the resource is composed of highly migratory species (tuna, mackerel, etc.), a survey in a localized area will give no real measure of the size of the stock and of the potential yield from it. The yield within the survey area in that case will be dependent not only on the size of the stock, which can only be estimated from a survey over the total range of its distribution, but also by the exploitation rate outside the survey area and the migration pattern of the stock.

If the available data suggest that pelagic species are likely to be a dominant part of the exploitable resource then the choice of survey method is likely to be an acoustic one with fishing by pelagic trawl or purse seine chiefly to identify the species which give the returned signals and to provide biological information on length composition, age, etc. of the stock. The choice of which of the acoustic survey techniques, described in Chapter 3, to apply will be largely determined by the equipment, and technical expertise of the staff, available. If possible an echo integration method is normally preferable. The same conditions, discussed in the previous paragraph, as regards the need for proper survey design apply to acoustic surveys as to fishing surveys.

There is a natural tendency on research vessel surveys to overload the programme with too many objectives, with the result that there is neither enough ship time nor scientific staff to collect all the data required adequately. No data should be collected the use of which is not clearly foreseen and which does not fit into the plan for achieving the survey objectives! As discussed in Chapter 2, an essential feature of good cruise, or survey,

planning is to decide the priority objectives and to define what data have to be collected at each station and how many stations have to be worked to achieve these objectives. On this basis one can then decide how long the ship has to be at sea and how many scientific staff are required to do this work. It is always a wise precaution to leave some margin of error to cover such events as bad weather, minor ship defects or illness amongst the staff. Only if the time and staff available are appreciably above this estimatedrequirement should lower priority objectives, such as hydrography, plankton sampling, etc., be included in the programme. The essential requirement on any exploratory fishing survey is to sample at sufficient positions to give an adequate coverage of the survey area and to measure accurately the size of the catch, its species composition and the length and age composition of the most important species from each haul. These are the basic data required to carry out the assessments described in Chapter 6.

Finally, the importance of systematic, accurate recording and timely reporting of all data collected during a survey, as discussed in Chapters 5 and 6, must be stressed. A well conducted survey is quite useless if the data are inaccurately recorded, if they cannot subsequently be identified to the data and position at which they were collected, or if they are subsequently lost due to a poor filing system.

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